SANDIA REPORT

SAND 2005-1926
Unlimited Release
Printed March 2005

Economics in Criticality and Restoration of Energy Infrastructures

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Sandia is a multiprogram laboratory operated by Sandia Corporation,
a Lockheed Martin Company, for the United States Department of Energy's
National Nuclear Security Administration under Contract DE-AC04-94AL85000.

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Abstract

Economists, systems analysts, engineers, regulatory specialists, and other experts were assembled from academia, the national laboratories, and the energy industry to discuss present restoration practices (many have already been defined to the level of operational protocols) in the sectors of the energy infrastructure as well as other infrastructures, to identify whether economics, a discipline concerned with the allocation of scarce resources, is explicitly or implicitly a part of restoration strategies, and if there are novel economic techniques and solution methods that could be used help encourage the restoration of energy services more quickly than present practices or to restore service more efficiently from an economic perspective.

Acknowledgements

Development of this work into a coherent product with a useful message has occurred thanks to the thoughtful support of several individuals:

Kenneth Friedman, Department of Energy, Office of Energy Assurance, provided the impetus for the work, as well as several suggestions and reminders of direction along the way. Funding from DOE/OEA was critical to the completion of this effort.

Arnold Baker, Chief Economist, Sandia National Laboratories, and James Peerenboom, Director, Infrastructure Assurance Center, Argonne National Laboratory, provided valuable contacts that helped to populate the authoring team with the proper mix of economists, engineers, and systems and regulatory specialists to meet the objectives of the work.

Several individuals provided valuable review of the document at various stages of completion, and provided suggestions that were valuable to the editing process. This list of reviewers includes Jeffrey Roark, Economist, Tennessee Valley Authority; James R. Dalrymple, Manager of Transmission System Services and Transmission/Power Supply, Tennessee Valley Authority; William Mampre, Vice President, EN Engineering; Kevin Degenstein, EN Engineering; and Patrick Wilgang, Department of Energy, Office of Energy Assurance.

With many authors, creating a document with a single voice is a difficult task. Louise Maffitt, Senior Research Associate, Institute for Engineering Research and Applications at New Mexico Institute of Mining & Technology (on contract to Sandia National Laboratories) served a vital role in the development of this document by taking the unedited material (in structured format) and refining the basic language so as to make the flow of the document as close to a single voice as one could hope for. Louise's work made the job of reducing the content to a readable length an easier process. Additional editorial suggestions from the authors themselves, particularly from Sam Flaim, Steve Folga, and Doug Gotham, expedited this process.

Contents

Preface

This document is designed to provide the widest possible audience with

- A comprehensive understanding of the state of the art of restoration and prioritization in the sectors of the energy infrastructure (including an understanding of the role of economics in restoration and in prioritization);
- An understanding of the state of the art in other infrastructures; and
- An understanding, from the perspective of a group of economists, systems analysts, engineers, regulatory specialists, and other experts as to how economic theory could be extended to identify particular assets that are most critical to the restoration process and critical to public safety and welfare.

Much of the first portion of the document is focused on background material beneficial to those without either a working understanding of the restoration process in the energy infrastructure, or of federal actions regarding critical infrastructure protection. This includes a description of federal directives and policies aimed at supporting national critical infrastructure, a detailed description of the concept and method of the work, an explanation of the elements of system planning in the energy sector (including the role of economics in each of these areas), and energy sector perspectives on restoration. Those familiar with these topic areas are encouraged to at minimum review the *Executive Summary*, page 9, the *Concept and Method of this Work*, section 1.3, page 14, and *Economic Considerations in Restoration*, section 1.4, page 15, before advancing to section 3.3, titled *Scale of Interest of this Effort*, page 24, which describes the metrics of disruptions considered by the authors in this effort. Even for the experienced reader, the earlier sections of this document will provide insight into the authors' perspectives on the energy infrastructure and its' operation.

From this point, the document provides the authors' perspectives on criticality, on the role of criticality in other infrastructures, objectives of and constraints on restoration, the costs and benefits associated with restoration, and stakeholder roles in restoration prioritization and economic decision-making. The document concludes with suggestions for future investigation, research, and application.

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Executive Summary

Activities associated with the restoration of energy services are but one of a set of operational planning measures for which an energy services provider prepares. It is in this preparatory phase (in the appropriate stockpiling, placement, and planning for use of manpower, equipment, and replacement parts) that the role of economics is most evident. Restoration of an energy system is, at its essence, a constrained optimization problem whose objective is to minimize costs (in the broadest possible sense of the word) subject to temporal, physical, economic, regulatory, and other constraining factors.

The importance of economics in restoration decisions is, in most cases, directly proportional to the magnitude and duration of the disruption and inversely proportional to the criticality of the load, asset, or action. Here, criticality is a measure of the consequences associated with the loss or degradation of an asset. Whether associated with a load, the supporting infrastructure, or the means and methods for restoration, economic factors will play some role in defining criticality, although under current operational procedures these may not have direct and substantive bearing on the restoration process itself.

The use of economics to identify which asset is most critical to restoration of service during a supply disruption depends upon the size or magnitude of the disruption, the scale of the area affected, and the duration of the event. Economics can help guide restoration decisions with fuzzy information, and economic theory is well developed for decision making under uncertainty.

Many of the actions taken during routine energy emergencies are carried out with little thought to direct economic ramifications. During emergency periods, the company's focus is on repairing the damage and restoring service at the earliest feasible time. Public health and safety is most often cited as the primary factor determining which loads are most critical and need to be reinstated first; however, even these automatic restoration responses can be characterized as rational economic decisions.

The economic consequences of a disaster affecting an energy infrastructure can be separated into two categories: the economic costs of the disaster itself and the economic costs of the restoration of services as a result of the disaster. This distinction is made because some consequences of the disaster cannot be restored: lives lost, sales lost, and so on. A complete and relatively accurate cost analysis of an energy incident includes all elements of costs incurred by the affected energy company as a result of an incident in both the short and long term, balanced by any monetary benefits derived from the response to the incident. The full costs of a loss may never be known. The social and political costs of such losses can be large and ultimately unquantifiable.

In the United States, wholesale energy markets permit prices to vary by time and location. These regional price variations create a temporal price topology that should reflect the marginal cost to meet demand to each individual location on the supply network. Assuming that such systems remain intact following a sudden network reconfiguration (such as loss of a critical node), the resultant real-time price signals could permit economically efficient allocation of available supplies, assuming market transparency, consumer knowledge, and an ability of consumers to benefit from responses to price signals. Markets could be modified to reflect "must serve" consumers (such as hospitals and other similar critical loads), in the same way that the supply side of said markets includes "reliability must run" producers (who exist in some market structures and are required to provide service no matter the cost or expected revenue so as to maintain system reliability).

Applicability of market principles to the definition of prioritization methodologies (in combination with other costs associated with disruption and restoration) is viewed by the authors of this study as a fruitful area for further analysis and research. As the magnitude and duration of a disruption increases, the potential increases for markets to realize economically efficient allocation of supply shortfalls. Economically efficient allocations of energy supplies are quite unlikely under all other schemes.

Although economics tools and constructs are implicitly or explicitly used in every type of restoration decision, economics has been underutilized for analyzing different response mechanisms for larger events of significant duration, particularly those events with a low probability of occurrence. This initial effort did not focus on such low probability, high consequence events; however, this is an area for which the authors of this study recommend further investigation. A similar situation exists for interdependencies between infrastructures (e.g., natural gas restoration activities that are dependent on commercial power). It may be fruitful to examine whether economic tools can be used to determine appropriate means to mitigate potential infrastructure failures due to interdependencies.

Additionally, other infrastructure sectors, such as telecommunications and banking and finance, have developed and implemented policy (in the form of regulation and day-to-day business dealings) focused on principles for determination of criticality, as well as measures for HSPD 7 related metrics of national well-being (such as Public Trust and Confidence in Government). These policies take a broader view than the service territory-centric view of the typical regulated energy services company, whose focus is on maintaining reliable supply of energy to consumers in their regulator-assigned service territory.

The telecommunications and banking and finance infrastructures have developed these principles and metrics based on consultation across their respective industries and in concert with other infrastructure sectors. An analogous effort within the energy infrastructure, possibly utilizing the metrics and methods followed by these other infrastructures as a template, is highly recommended (especially for the petroleum infrastructure). It is particularly recommended for the above-described low probability, high consequence events which span multiple service providers and sectors of the energy infrastructure whose consequences impact other infrastructures. Understanding the interdependences of various critical infrastructures is necessary when building the metrics and methods to be followed within the energy industry. This should to be addressed in order to minimize the economic repercussions of a low probability, high consequence event spanning multiple infrastructures (e.g., gas, electric, communications, water and transportation).

One way of incorporating economic impacts in the broad context is through the development and application of computer models. In this realm, the Department of Energy and other federal agencies have made significant investment over the last decade in critical infrastructure modeling in general, and in energy systems modeling in particular, developing models that integrate both the physical performance of systems and the economic consequence of disruption to said systems. Further examination is required to gauge the usefulness of these tools in providing an objective examination of problems facing real-world decision makers, both to guide restoration planning and to aid in prioritization (before and during an event).

Nomenclature

ACH	Automated Clearing House
AGA	American Gas Association
APGA	American Public Gas Association
API/NPRA	American Petroleum Institute and the National Petrochemical and Refiners Association
CAAP	Critical Asset Assurance Program
CWA	Clean Water Act
DHS	Department of Homeland Security
DoD	United States Department of Defense
DOE	United States Department of Energy
ERC	Emergency Response Center
ERP	Emergency Response Plan
ERT	Emergency Response Team
ES&H	Environment, Safety & Health
FBIIC	Financial and Banking Information Infrastructure Committee
FERC	Federal Energy Regulatory Commission
HILP	High Impact, Low Probability
HSPD	Homeland Security Presidential Directive
IA/AP	Information Analysis and Infrastructure Protection
INGAA	Interstate Natural Gas Association of America
IRT	Initial Response Team
LDC	Local Distribution Company
NARUC	National Association of Regulatory Utility Commissioners
NCS	National Communications System
NRC	Nuclear Regulatory Commission
NS/EP	National Security & Emergency Preparedness
OEA	Office of Energy Assurance, United States Department of Energy
OPA 90	Oil Pollution Act of 1990
OPS	Office of Pipeline Safety
POL	Petroleum, Oil, and Lubricants
PUC	Public Utility Commission
QA	Quality Assurance
SSA	Sector-Specific Agency
SRT	System Restoration Team
TSP	Telecommunications Service Priority

Economics in Criticality and Restoration of Energy Infrastructures

1. Background

1.1. Homeland Security Presidential Directive 7

On December 17, 2003, Homeland Security Presidential Directive (HSPD) 7 was released. The purpose of this directive is to establish "…a national policy for Federal departments and agencies to identify and prioritize United States critical infrastructure and key resources and to protect them from terrorist attacks." This directive followed a long succession of presidential directives aimed at identifying and protecting critical national infrastructure, including Executive Order 13010 (signed July 15, 1996) and Presidential Decision Directive 63 (signed May 22, 1998). HSPD 7 went further, specifying lead federal agencies (Sector-Specific Agency, or SSA) for each of the infrastructures and key asset types as specified by the Department of Homeland Security (DHS). These SSAs are directed to:

> (a) collaborate with all relevant Federal departments and agencies, State and local governments, and the private sector, including with key persons and entities in their infrastructure sector;
>
> (b) conduct or facilitate vulnerability assessments of the sector; and
>
> (c) encourage risk management strategies to protect against and mitigate the effects of attacks against critical infrastructure and key resources.[1]

1.2. Role of the Department of Energy under HSPD 7

The United States Department of Energy (DOE) is designated as the SSA, for "energy, including the production, refining, storage, and distribution of oil and gas, and electric power except for commercial nuclear power facilities"[2]. Additional responsibilities are defined for DOE in conjunction with DHS and the Nuclear Regulatory Commission (NRC), regarding protection of nuclear reactors, nuclear materials (and facilities that fabricate said materials), and transportation, storage, and disposal of nuclear materials and waste.[3] DOE also has a role to play in conjunction with the nation's hydroelectric dam owners and operators (including other Federal entities) and DHS, which is responsible to "…coordinate with appropriate departments and agencies to ensure the protection of other key resources including dams…"[4, 5]

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[1] HSPD 7, § 19
[2] HSPD 7, § 18(d)
[3] HSPD 7, § 29
[4] DOE's statutory responsibilities, many of which direct activities explored in this report on restoration, fully support HSPD 7 roles and responsibilities. As a general matter, Congress has not legislated using

There are, however, some notable but traditionally consistent exceptions regarding the energy sector, related to the transportation of natural gas and oil (and other hazardous materials)[6] and to the coordination of protection activities for pipeline systems.[7] These exceptions are consistent with the traditional mission of the Department of Transportation's Office of Pipeline Safety, "[t]o ensure the safe, reliable, and environmentally sound operation of the nation's pipeline transportation system."

Under HSPD 7, SSAs (including DOE for the Energy sector) and DHS are to collaborate with the private sector "…to identify, prioritize, and coordinate the protection of critical infrastructure and key resources…"[8] Moreover, HSPD 7 indicates that "On an annual basis, the Sector-Specific Agencies shall report to the Secretary on their efforts to identify, prioritize, and coordinate the protection of critical infrastructure and key resources in their respective sectors."[9]

This effort is designed to provide support to DOE in fulfillment of its mission as the Sector-Specific Agency for the Energy Sector under HSPD 7, through development of an understanding regarding the current state of the art in the Energy sector for the prioritization of restoration of services, more specifically regarding the role served by economic factors in prioritization.

1.3. Concept and Method of this Work

1.3.1. Concept

DOE's Office of Energy Assurance (OEA) seeks to understand how economic concepts and principles are used to prioritize energy infrastructure restoration activities. In addition, OEA would like to know how economic theory could be extended to identify particular assets that are most critical to the restoration process and critical to public safety and welfare. This effort attempts to identify whether economics, a discipline concerned with the allocation of scarce resources, is explicitly or implicitly a part of restoration strategies, and if there are novel economic techniques and solution methods that could be used help encourage the restoration of energy services more quickly than present practices or to restore service more efficiently from an economic perspective.

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terms such as "criticality" and "restoration" of energy assets. See, e.g., Federal Power Act, as amended, §202(c) (The Secretary of Energy has authority in an emergency to order temporary interconnections of facilities and/or the generation and delivery of electric power. This authority may be utilized upon a petition from a party requesting the emergency action or it may be initiated by the Administration on its own initiative) and the Natural Gas Policy Act, Title III, Sections 301-303, 15 U.S.C. § 717 et seq. (DOE may order any interstate pipeline or local distribution company served by an interstate pipeline to allocate natural gas in order to assist in meeting the needs of high priority consumers during a natural gas emergency).

[5] HSPD 7, § 15

[6] HSPD 7, § 2 (f)

[7] HSPD 7, § 15

[8] HSPD-7, § 25(a)

[9] HSPD-7, § 35

Conceptually, the study goals seem relatively straightforward; however identifying implicit decisions (with implicit costs) that are made in the heat of an actual restoration event, with attributes that do not fit neatly into any single theoretical construct, can be extremely complex. Service managers have explained that during a major supply disruption, their goal is simple, "restore service to the largest number of customers as quickly as possible." Typically, there are procedures in place for the restoration of energy services given specific knowledge of the disruption. They are followed with high fidelity, and are exercised regularly. However, these decisions are often made in the reality of a large scale disruption where incomplete information on the state of the system exists. Less attention has been paid to quantifying the benefits of the restoration process as an aid to prioritization.

1.3.2. Method

Economists, systems analysts, engineers, regulatory specialists, and other experts were assembled from academia, the national laboratories, and the energy industry to discuss present restoration practices (many have already been defined to the level of operational protocols) and how economic principles are explicitly or implicitly used to establish and implement a restoration plan. Informal inquiries were also made to persons who have the responsibility to activate emergency response teams and emergency response centers, and to dispatch crews and equipment to repair major energy infrastructure disruptions.

The study team addressed a wide range of topics including how restoration decisions are made within a single infrastructure and how restoration in a single infrastructure impacts restoration activities in other infrastructures. Until recent years, optimizing restoration activities across infrastructures was an ad hoc activity at best.

The method employed to approach this study was to outline issues across the breadth of current restoration practices, break restoration practices into component parts or separate identifiable steps in the restoration, and examine how economics is used to aid decisions in each step of the process. The method comprises a review and synthesis of theories and practice with an emphasis on anecdotal information rather than undertaking a lengthy, involved modeling of the decisions themselves.

1.4. Economic Considerations in Restoration

A standard economic approach to measuring benefits is a welfare measure; the simplest of these would be a measure of producer and consumer surplus.[10] A disruption distorts a functioning market and limits the available quantity of a good or service, which results in a welfare loss. The *benefit of a restoration* is the elimination of that welfare loss. These benefits can be weighed against the restoration costs.

The traditional welfare triangle is shown in Figure 1. A disruption reduces energy deliveries and creates a welfare loss that is defined by the triangle formed between the

[10] This discussion of welfare is intended to be illustrative. It is not necessary to consider more complex welfare measures such as compensated variation, etc.

supply and demand curves, between the equilibrium quantity, Q*, and the level of delivery during the disruption. This welfare triangle is further comprised of producer and consumer surplus, i.e., the parts of the triangle below and above the equilibrium price, P*. While producer welfare losses are not to be ignored, the primary focus of benefits of restoration are most likely on the consumer side.

It is convenient to think of many consumers (or customer classes) each with their own demand curves. In that case, the economic consideration of benefit is simply the sum of these welfare triangles. This distinction is important since an outage does not follow the dictates of an economic market, i.e., energy does not automatically flow to those customers with the highest willingness to pay, but instead will impact all customers in the affected area. If different classes of customers have different needs, then this influences the economic consideration. For example, Figure 2 shows a customer class with very high willingness to pay (inelastic demand). These customers may be thought of as a "critical load" (from an economic perspective) because the welfare loss is much larger than for typical customers. As the demand curve becomes steeper, the benefit of restoring this type of customer grows dramatically. If the customer need for energy is so large that *the loss always is greater than the cost of restoration*, then this provides an economic definition of *critical load*. Common examples of critical loads include hospitals, other public safety uses, or single or multiple residential customers at risk of death due to the disruption.

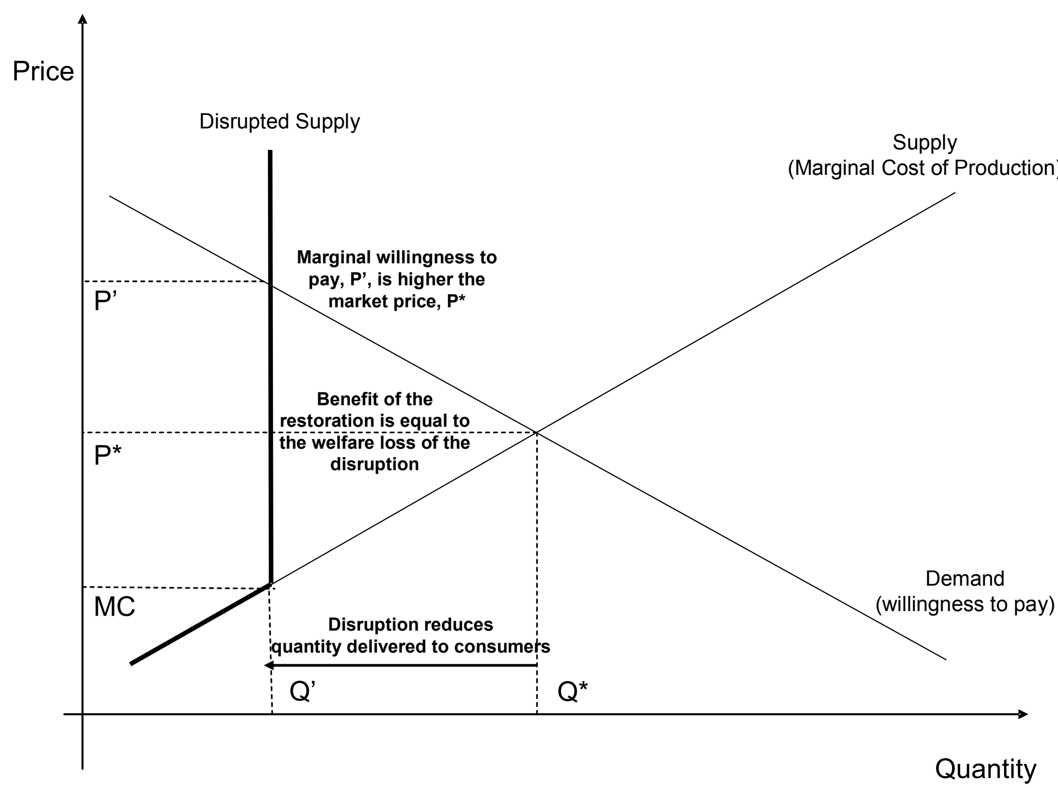

Figure 1. Traditional Welfare Triangle.

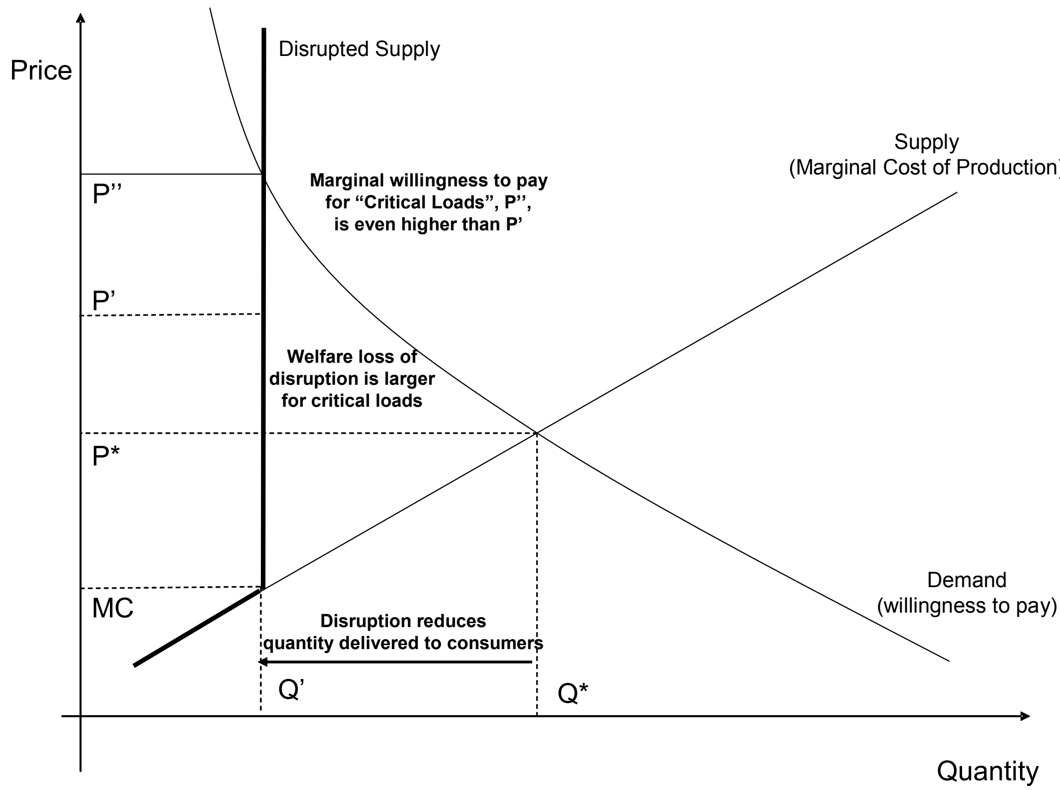

Figure 2. Welfare Triangle for Customer with Inelastic Demand.

The above example provides a simple economic framework for measuring benefits. These benefits can be compared to the restoration costs and be used for prioritization. In a real outage things are never simple. The consumers' losses may differ temporally and spatially. Restoration cannot always be perfectly targeted to critical loads. However, basic economic principles do play a role in both the system and restoration planning at the foundation of any restoration activity.

2. System Planning

2.1. Operational Planning

Energy system infrastructures are normally built and operated in a robust manner, so that they are capable of withstanding the failure of individual components without a large portion of the system being shut down. This is accomplished in both the resource planning and system operation stages.

The resource planning process involves determining the proper amount and placement of infrastructure components to allow the system to be operated in a reliable and efficient manner. This process intentionally builds in redundancy, so that the system can handle a range of foreseeable outage events. Typically, resource planners attempt to maintain some minimum standard of reliability. These standards could include loss of load probability or expectation, expected unserved energy, or capacity/reserve margins.

Normal system operations typically include outage contingency analyses. These are usually first order analyses, i.e., determine whether the system can withstand any single equipment outage or failure. In cases where limited second order contingency analyses are performed, the outage combinations are usually chosen heuristically, based on operational experience.[11]

For example, contingency planning for Petroleum, Oil and Lubricants (POL) operators is mandated by the Oil Pollution Act of 1990 (OPA 90).[12] Oil companies analyze options for response to accidental oil pollution under varying sets of assumptions. Taking into account cost and schedule considerations, they attempt to calculate optimal configurations of cleanup resources in terms of locations, types, and quantities of cleanup equipment that should be strategically stockpiled in response to estimates of long-term needs. Well before actual need, oil companies operating in a region attempt to gain a broad perspective on their role and responsibilities in a regional clean-up system.

Federal law requires[13] certain facilities that store and use oil to prepare and submit plans to respond to a worst case discharge of oil and to a substantial threat of such a discharge. These plans also include responding to lesser discharges as appropriate.

2.2. Pre-Incident Emergency Planning and Protocols

Pre-incident planning exercises attempt to maintain prudent business operations practices during supply disruptions by applying sound engineering principles under practical operations constraints in an economically efficient manner. Infrastructure entities, including businesses, regulators and other participants, pre-plan to have properly trained employees and adequate inventories of materials and contractors available to handle system operations and emergency conditions based on past history and the risk/probability of particular events occurring. Some events such as catastrophic losses are beyond the scope of pre-planning exercises. The costs of owning, outsourcing, or bearing the financial risks of not maintaining these back up resources is weighed against the potential economic losses that could be incurred in their absence. Pre-planning conceivably lowers a company's financial risk by having replacement parts available, the lack of which could raise costs significantly during an incident.

Economics plays a major role in upfront proactive planning that determines the number of available spare parts and other materials. Planning allows businesses and regulators to explicitly consider the costs and benefits of the maintenance of a stockpile of emergency materials, coordination of response efforts, and communication protocols among agencies, neighboring utilities, customers and public media agencies.

[11] For oil and natural gas pipeline systems, these second order contingencies can also be identified through the use of hydraulic models.
[12] Refer to 33 USC 2701 et seq.
[13] *See* Section 311(j)(1)(C) of the Clean Water Act (CWA, codified at 33 U.S.C. 1251).

For example, when new customers are added or a pipeline facility is replaced due to public road improvements or corrosion, the engineering department at a utility will review the economics of short- and long-term investment in a larger pipe or regulating station than the one being replaced in terms of service, system integrity, and redundancy benefits. The redundancy design practice takes into account system restoration during crises and/or provision of back feed to another system.

In addition, transmission pipeline and local utility companies conduct system surveys on an annual basis for peak and off-peak supply/demand conditions to validate modeled system operating characteristics against actual field measurements. Based on this information, a company may make substantial investments to improve the reliability and safe delivery of the product to its customer taking into consideration redundancy and backup system design that could provide the advantage of rapid restoration during an emergency scenario.

Emergency planning identifies in detail each organization's responsibilities, emergency materials inventory, personnel, and contractor resources to be made available in the event of a disruption. The organization's responsibility chart identifies the roles and activities of the officers, managers, supervisors, employees and contractors during an emergency. Specific use of equipment and communication protocol guidelines and procedures for reporting in an emergency situation are explained in detail.

Generally, utility companies conduct emergency exercises annually to test the restoration process. For example, The U.S. Department of Transportation Office of Pipeline Safety (OPS) requires that pipeline companies have formal emergency response plans, and annual drills to test those plans. Additionally, the National Response System provides a mechanism for emergency response to discharges of oil into navigable waters of the United States and releases of chemicals into the environment. Event scenarios drawn from historical experience are tested and incorporated into the emergency planning. In practice however, it is impossible to consider all types of potential scenarios.

As discussed earlier, transmission pipeline companies and local utilities must comply with local, state, and federal regulatory bodies. Communications to these regulatory agencies become vital during the response to an emergency. To keep the public (as well as critical customers) informed, close cooperation with local media agencies is vital. Government regulations in the area of safety often dictate how businesses prepare and execute their response and recovery plans.

Mutual aid programs are used by utilities and local governments in preparation for response and recovery to large incidents. These programs provide well-established practices and networks for mutual benefit. For example, companies located along the Houston Ship Channel have mutual aid agreements for fire fighting equipment and personnel. Most terminal and refining companies enter into similar types of agreements. There are less formal agreements between oil companies for "borrowing" supplies when an emergency arises. These agreements are generally verbal and based on a "hand shake" in field environments. The types of supplies involved cover anything from pipe to compressor parts. These informal agreements are generally based on personal contacts in field offices. As people leave the workforce and new personnel or automated systems take over, these informal agreements are not likely to be perpetuated. Pre-planned mutual aid agreements are more efficient and dependable.

Mitigation/prevention actions begin with the identification of critical components that are vulnerable to probable hazards. The cost of any mitigation/prevention investment has to be justified in comparison to estimated losses. Expensive projects may take several years to fund and complete. Low-cost activities for critical components can be accomplished in the meantime. The mantra for incident management is "price does not matter in an emergency," especially when considering potentially catastrophic environmental and economic effects, such as a large-scale oil spill. Given the high costs of long-term environmental restoration, it is generally considered to be more prudent to spend $4 million in pre-planning to ensure oil spill containment within the first 8 hours than to spend $40 million later to clean up contaminated areas as a result of limited pre-planning.

3. Restoration

There are several differing interpretations of the term restoration. It is therefore worthwhile to examine individually the meaning of this term from the point of view of the electric power sector, the POL sector, and the natural gas sector.

3.1. Electric Power Infrastructure Sector Perspective

In the electricity sector, large supply disruptions usually lead to an executive decision to activate an emergency response team (ERT) which follows an Emergency Response Plan (ERP) and may require staffing an emergency response center (ERC) for larger outage events.

ERT members are selected principally on the basis of actual operational experience in load management, generation dispatch, and transmission/distribution to manage restoration activities. Usually, the team will also include administrative personnel to expedite procurement of parts and supplies. Determining the nature and extent of the problem can be very time consuming and can be more difficult than it would seem once restoration begins because the system must be restored keeping all three parameters (load, generation and transmission) in balance.

Frequently, restoration activities for large supply disruptions are centered on transmission failures. Although generation asset failures or a lack of sufficient generating capacity can cause disruptions that cascade throughout the system, it is the transmission system that requires the most complex decision making during restoration, largely due to the difficulty of ascertaining the operational status of transmission line segments. Transmission assets are dispersed, may continue to function when damaged, and often require line crews to walk the entire system to determine the extent and nature of the operational problem.

Public health and safety have been identified as the first rule of restoration in practice. Second in priority of concern is securing the system. Electricity generation and transmission assets have often been the targets of vandals, protestors, and scavengers. Most utilities and system operators have their own security forces, and, if the problem is believed to be related to a breach of security, the ERT will send personnel to secure the asset before assessing the damage and initiating repairs.

Once the ERT is assembled (or in communications contact), the team often remains activated on a 24-7 basis until the system is restored. Once the system is secure and the health and safety of the general public and repair crews can be assured, the restoration activity is coordinated by a System Restoration Team (SRT). Generally, the SRT has a defined set of protocols and usually will attempt to restore power to hospitals, fire stations, emergency medical personnel, and military bases without regard to costs. These are critical loads to serve. The SRT will then proceed with the restoration of the rest of the system, generally operating on the principle of restoring service to the greatest number of people first, and then restoring service to a rank order of customers and load centers depending upon the magnitude of the damage, the accessibility of damaged assets, the availability of parts, and other factors.

Restoration is particularly difficult during events like hurricanes and ice storms. In the latter instance, service can be restored during the day when temperatures climb, only to be put out of service again overnight when rain or snow freezes to transmission and distribution lines. Hence, restoration is an iterative process rather than a one-time sequence of events.

3.2. POL and Natural Gas Infrastructure Sectors Perspective

The oil and gas industries are each made up of a few very large companies and many smaller companies. Natural gas and POL differ from electricity in that they can be conveniently stored, allowing production and consumption to vary independently. The storage of natural gas and refined petroleum products near demand areas (away from the producing areas) provides additional flexibility in restoration activities.

Similar to electric utilities, local distribution companies (LDCs) are given franchise areas for natural gas distribution by state public utility commissions (PUCs). In return for having essentially a local monopoly to distribute natural gas, each LDC is expected to make all reasonable efforts to prevent interruptions of service. When interruptions occur, the LDC shall reestablish service with the shortest possible delay, consistent with general safety and public welfare [Illinois 2004].

Unlike disruptions to the electric power system, disruptions to natural gas service are infrequent and typically confined to relatively small areas. When compared to the number of customers affected by electric power outages and the size of their associated service territories, the numbers are small.[14] The number of customers affected, however,

[14] As an example, the largest number of customers losing gas service at any one time within the Chicago Metropolitan Area (which encompasses Cook, DuPage, Kane, Lake, McHenry, and Will counties in

has a special implication for natural gas service restoration, as the procedure for restoring service (generalized below) involves direct customer interaction. Visiting each individual customer is tedious, time-consuming, and costly, but is conducted with customer safety as the primary concern [Cirillo 2003].

A generalized procedure for the entire natural gas service restoration and pipeline rupture repair process is broken into twelve steps, some of which can be performed simultaneously. Each step, and factors including economics that inherently affect the time and resources needed to complete each process, are briefly described below.

First Assessment – After a call is made to the dispatch center or a SCADA system alerts the utility of a possible problem, qualified employees are sent to the site to assess the problem. Although it is possible that this crew can repair minor problems and restore service on the spot, only non-trivial ruptures are considered here. Major sources of uncertainty affecting the time needed to complete this step include: time of day, day of week/holiday, weather, terrain and location, number of concurrent crises, and outside interference. If there is a suspected break of a liquid pipeline, it is shut down immediately.

Mobilize Response Team – Once the initial assessment is made, a larger crew might be mobilized and sent to the site, and an additional support team is activated at headquarters. The time needed to complete this step may be affected by similar sources of uncertainty as mentioned above.

Activate Support Team – While the response team is mobilized, a liaison/support team of utility managers might be activated to oversee the response team's efforts, locate maps and diagrams, deal with the press in cases of explosions or major outages, and coordinate with representatives from police and fire departments.

Identify the Extent – Identify the outage areas, customers involved and shut off customer valves. Follow 'HELP": Is there a hazard? What is the extent? Protect life! Protect property!

Reconfigure System – Depending on the nature and severity of the rupture and whether or not critical customers are affected, the response team may have the option of reconfiguring the surrounding pipeline system to keeping gas flowing to customers who have not lost service.

Gain Control and Shut Down System – Fires (if any) are extinguished and the site is made safe to begin the repair. Major sources of uncertainty that may affect the time needed to complete this step include weather, pipeline diameter, and pipeline pressure.

Gather Additional Equipment and Material – Concurrent with the previous step, additional equipment, cranes, valves, fittings, pipes or other materials may be needed at

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Illinois) is on the order of 4,500.

the site, and additional time may be needed to gather them from utility or manufacturer warehouses and to transport them to the site.

Gather Non-Standard Equipment and Material – If the pipeline is a non-standard diameter[15], additional time may be needed to obtain special fittings or stopping equipment. More severe events may also require additional time.

Repair/Replace Pipeline – This step may involve trenching, welding, positioning the pipe, X-raying, testing, and other quality assurance (QA) procedures.

Startup of the System or Pipeline – Purge, pressurize, and reestablish system or pipeline functionality.

Relight Pilot Lights – If a rupture causes loss of gas service, field workers typically shut off customer valves. When gas flow is renewed in the pipelines, a sufficient number of workers are sent to relight customer pilot lights to ensure restoration within a reasonable amount of time. One worker can typically relight four to six pilots per hour.

Environmental Restoration – This is particularly important for pipelines and is also an issue in urban distribution areas.

A natural gas transmission company has the right to interrupt service or reduce delivery amounts immediately in cases where there is natural gas leakage in the transmission network, where the safety of the transmission network is under serious risk, or where the pressure or the quality of natural gas in the transmission network would present danger to people or goods if delivered. The natural gas transmission company is expected to safely restore the natural gas supply to customers once the emergency is over.

Similar to natural gas pipeline companies, petroleum pipeline companies typically follow a tiered response concept for oil spills occurring along the pipeline or at pump stations. A tiered response is defined as adding additional layers of personnel and equipment to an incident until the initial emergency is secured and response efforts clearly demonstrate a beneficial effect on the incident. Petroleum pipeline companies have developed and implemented many response procedures and programs to reduce risk of employees to hazards (e.g., fire, vapors, noise, excavations, cranes, working over water, slings, etc).

The maintenance and operating crew based at the nearest pump station, tank farm, or other pipeline facility will typically form the Initial Response Team (IRT). If the IRT is unable to completely handle any spill, they notify the Incident Commander of the situation, take actions to protect sensitive areas, and initiate containment until help arrives. The Incident Commander marshals additional personnel and equipment from within his/her jurisdiction, and may call on a tiered response.

The oil and gas infrastructures share a common potential for cascading failure, in which a failure in one infrastructure leads to a failure in another infrastructure. Most oil and gas

[15] Standard pipe diameters are 2, 4, 6, 8, 10, 12, 16, 20, 24, 30, 36, and 42 inches.

operations are highly dependent on commercial electricity for their operations. An electric power failure can shut down a petroleum refinery dependent on commercial power. In the event of a rotating electrical outage in their service block, the refinery would have to perform an emergency shutdown of all of their operations. A refinery required to undergo an emergency shutdown can take up to 1 to 2 weeks to return most operating units to full normal operation, assuming that no equipment was damaged during the shutdown. Unfortunately, the very short notice (possibly only minutes) of a rotating electrical outage, and the complexity of emergency shutdown procedures significantly increases the potential for equipment damage. If electricity outages were to hit one of these refineries frequently, the refinery might choose to remain down for extended periods of time rather than undergo the high costs of repeated emergency shutdowns and restarts. Thus, relatively minor events in one infrastructure can have a disproportionate impact in other infrastructures (and sectors of the economy).

3.3. Scale of Interest of this Effort

3.3.1. Disruption Size/Scale/Duration

The use of economics to identify which asset is most critical to restoration of service during a supply disruption depends upon the size or magnitude of the disruption, the scale of the area affected, and the duration of the event. Very large outage events with a very short duration, such as a generation or transmission fault that causes a frequency or voltage problem but is solved in a matter of minutes by rerouting power or by bringing additional generation online, probably does not require economics to efficiently sequence the restoration process. Very small events that impact a small part of the service area, a small part of total load, or a small number of customers are similarly resolved without regard to difficult choices being made based on economic efficiency. In both cases, restoration proceeds as quickly as possible with restoration decisions driven by mandated protocols, the engineering feasibility of proposed actions, and access to parts or crews to fix the problem.

However, a large restorative action requiring executive action and a coordinated response would involve many short-term and longer-term economic decisions. Generally, as event size, scale and duration increase, the importance of economics, the science of allocating scarce resources, also increases. At the other end of the spectrum, there are cases in which it is uneconomic to restore service at all, but the decision is driven by federal and state regulations or other requirements mandated by law.

A fundamental premise of achieving optimal economic efficiency is acquiring perfect information. Perfect information, as a practical matter, is a near impossibility. As the quality of information decreases, the likelihood of realizing an economically efficient use of scarce resources decreases. However, economics can help guide restoration decisions with fuzzy information, and economic theory is well developed for decision making under uncertainty.

Economics can help guide restoration decisions, including those that require active managers to accept the possibility of doing nothing until the extent of the problem is known.[16] Economics can also play a significant role in guiding restoration decisions affecting multiple infrastructures. An electricity outage can affect telecommunications, traffic lights, water and sewage pumps, and other assets. Understanding the economic characteristics of these infrastructure assets and their impact on public health and welfare can provide guidance for very complicated (and possibly counterintuitive) restoration decisions. For example, a lightning storm may cause outages over a wide area affecting many customers, but a single strike at a transformer servicing a telecommunications switching center has repercussions not only for customers in the area affected by the disruption to the electric power system, but also for telecommunications customers served by the switching center, and for those elsewhere who are dependent on interrupted telecommunications and electric power customers for commercial services and other business transactions.

This investigation will focus on the contribution of disruptive events of sufficiently large-scale and typical duration. This includes events such as the August 14, 2003 blackout; the August 19, 2000 El Paso Natural Gas pipeline rupture near Carlsbad, New Mexico; and the impacts of the "ILoveYou" virus on oil and natural gas sector cyber and physical infrastructure in May 2000. The authors suggest further investigation into the role for economic analysis of disruptive events that are large in scale, have a longer duration, an extended time to recovery, and a low probability of occurrence.

3.3.2. Infrastructure Elements/Assets

Infrastructure assets include both the tangible, physical plant and equipment, and the human capital embedded in the operations of facilities. For the purposes of a restoration activity, elements of an infrastructure are usefully defined to the level within which an action can be initiated. Going to a higher level of resolution increases computational complexity and does not necessarily lead to better decisions. The higher the level of aggregation in decision processes the more quickly the conceptual construct of a restoration activity can be understood. For example, if a utility is attempting to black-start generation across a service region, it may be more useful to discuss restoration strategy by considering plants, not individual units, when sequencing the start-up. This description of the parameters considered by the participants, by its very nature, requires the inclusion of assets not specifically called out as under the direct responsibility of DOE as the SSA for the energy sector under HSPD 7. This flexibility is crucial, as the responsibilities specified within HSPD 7 do not form a one-to-one mapping with the operational and business lines that serve an essential role in determining the path that will be taken by industry in performing and scheduling restoration activities.

4. Criticality

Criticality is typically defined as a measure of the consequences associated with the loss or degradation of a particular asset within an infrastructure. The more the loss of an asset

[16] Restoration of service may have to wait but ensuring that the area is safe and responding to immediate danger or risk cannot wait.

threatens the survival or viability of its owners, of those located nearby, or of others who depend on it (including the nation as a whole), the more critical it becomes [United States Department of Defense (DoD) 1998].

Consequences can be categorized in a number of ways: economic; financial; environmental; health and safety; technological; operational; and temporal. The loss of an asset might also reduce a firm's competitive advantage, not only because of the financial costs associated with its loss, but also because of the loss of technological advantage or loss of unique knowledge or information that would be difficult to replace or reproduce.

Another impact to be considered is the potential damage to reputation for individual firms after the loss of a critical component. The American Petroleum Institute and the National Petrochemical and Refiners Association (API/NPRA) in their Security Vulnerability Assessment Methodology for the Petroleum and Petrochemical Industries also suggest considering the possibility of "excessive media exposure and resulting public hysteria that may affect people that may be far removed from the actual event location." [API/NPRA 2003]

The DoD Critical Asset Assurance Program (CAAP) views criticality (or minimum essential) as a function of time and situation for two classes of assets: (1) those assets necessary to maintain a defined level of service for a given window of time within an infrastructure sector, and (2) those assets necessary to connect identified users to that service. Service level, service duration, and service connectivity requirements are driven by the user [DoD 1998].

Criticality can also be viewed as a spectrum of choices or alternative courses of action to restore equilibrium(s) to infrastructure(s). The spectrum is defined by engineering efficiency on the one end of the spectrum and social welfare on the other. Economic methods assist in allocating scarce resources to restore system equilibrium. The introduction of economics into the restoration process allows quantifiable consideration of questions such as 'How do we choose what to do to restore the system(s), and when?' while allowing decisions to be made by asset owners.

4.1. Of a Restorative Action

Criticality of a restorative action, where action is meant to be a part of the entire restoration activity, can be expressed in a number of useful ways. Criticality might focus on an action (or group of actions) specific to restoring the entire system, or an action (or group of actions) specific to restoring a critical load, such as a hospital or military base. Another definition of criticality for a restorative action might be measured by the aggregate benefit, however measured, that may accrue to one or more parties (end users, energy companies, regulators or other stakeholders). For example, early in the restoration process, procurements to acquire parts or crews not otherwise readily available are probably on the critical path for restoring the entire system.

A critical restorative action could be that step which minimizes the time to restore the entire system or minimizes the costs of the activity or the restoration process.[17] In this context those steps that maximize revenue to the service provider or revenues to other stakeholders could be considered critical (under the premise that safety is not compromised). In general, since service providers try to restore service as quickly as possible subject to the constraint of what the end users, energy companies, regulators and other stakeholders would consider reasonable costs, this constrained optimization approach is yet another valid way to view the problem of ranking the importance of restorative actions.

Another economics-based approach would involve the identification of critical assets within an infrastructure, and their valuation for the needs of this and other infrastructures. Conceptually, the approach combines discounted revenue and cost streams associated with each restoration plan allowing direct comparisons among different restoration protocols and restorative actions within activities. The advantage of this approach is that restorative actions that can be envisioned a priori can be examined in detail and defined as protocols. A protocol defined over the course of time, with analytical support and identified contingencies, offers a great advantage over ad hoc analysis. Defining the protocols necessary to encompass natural disasters and possible attacks by vandals, scavengers, protestors or terrorists would greatly facilitate restoration activities.

The AGA/INGAA/APGA *Security Guidelines* (2002) incorporate a risk-based approach for gas companies to consider when identifying critical facilities. It is recommended that the consequences to the system be analyzed by examining the loss of a key asset in terms of the following three factors: analysis of the function of the system with the loss of the asset; ease of replacement, in terms of both the availability of spare parts and the time required to manufacture replacement components if spare parts are unavailable; and redundancy of the function of the asset. This approach is somewhat unique in that it implicitly takes into account the restoration duration in its approach to determining critical facilities.

The criticality of a restorative action can be viewed as a metric of the benefit that action would yield. Such benefit may accrue directly or indirectly to multiple parties (end users, energy companies, regulators, other critical infrastructures, and others) and economic principles can be applied in aggregating the various benefits into a useful index.

4.2. Of an Energy Infrastructure Asset

The extreme importance of critical infrastructures to modern society is widely recognized. These infrastructures are complex, interdependent, and ubiquitous; they are sensitive to disruptions that can lead to cascading failures with serious consequences. Protecting the critical infrastructures from terrorism, human generated malevolent attack

[17] In cases where a complete system repair will take some time (due to replacement parts or equipment availability) temporary measures (e.g., above-ground mains) may be taken to minimize time to restore service to customers.

directed toward maximum social disruption, presents an enormous challenge. Recognizing that society cannot afford the costs associated with absolute protection, it is necessary to identify the critical locations in these infrastructures.

The criticality of an energy infrastructure asset can be measured in terms of the dependence of the system's operational capacity on the operative status of the asset. In other words, if any particular piece of the whole were out of service, what would happen to the rest of the system? Any single electrical generation unit is usually not a critical energy infrastructure asset unless the system is operating at or near capacity and no other generation units are available to replace it. Generation units are regularly scheduled for maintenance and are taken off-line at regular intervals.

In general, an electrical transmission or distribution line segment would not be considered a critical energy infrastructure asset if power could be rerouted around the line fault. However, a particular bus or substation could very well be critical if it serves a critical load, such as a pumping station (water, sewer, gas), control center (telecommunications, electrical transmission and distribution, vehicular or air traffic, financial services, etc.), military base or hospital.

The criticality of an energy infrastructure asset can also be viewed from the perspective of restoration. Therefore, criticality may depend upon a combination of factors: is the asset necessary to serve a critical load, is the asset quickly replaceable, is the asset hugely expensive, or is the asset critical to keep the condition of the system from cascading failure?

The Homeland Security Act of 2002 (P.L. 107-296) and other Administration documents have assigned the Department of Homeland Security specific duties associated with coordinating the Nation's efforts to protect its critical infrastructure, including using a risk management approach to set priorities. Many of these duties have been delegated to the DHS Information Analysis and Infrastructure Protection (IA/IP) Directorate.

"Criticality" of an energy infrastructure asset is defined to be an index of the cost that a disruption of that asset would impose. Such costs may fall on multiple parties (end users, energy companies, regulators, others) and economic principles can be applied in aggregating the various costs into a useful index. Criticality and restoration legal and regulatory history have generally not explicitly taken into account economic considerations.

4.3. Of a Customer Load

When energy service companies experience a major outage, one of their foremost considerations is the order of precedence in restoring service to individual customers. The order of precedence can vary by type of infrastructure, restoration system constraint (how the system must be placed in service), and the time of year. During severe winter weather, natural gas utilities typically restore service to residential and critical customers before large customers to mitigate damage to homes and protect the public health.

Telecommunications and electric power infrastructures typically reverse this order, restoring service to large customers (or customer groupings) first.

From an economic perspective, restoring service to large customers before small customers minimizes losses due to business interruptions and lost sales to the service provider. However, public health and safety is most often cited as the primary factor for determining which loads are most critical. Since most companies have considerable experience dealing with outages and conducting emergency operations exercises, the criteria for making decisions about which loads are viewed as most critical are usually made before an outage occurs.

Recent hurricanes in Florida have brought considerable attention to the decision criteria used to identify which loads are more critical than others. For restoration of electrical service, utilities place first priority on hospitals, police stations and fire stations. Mass media communication companies, particularly television and radio stations, fall into the second tier, followed by street lighting and traffic signals. Commercial districts are a fourth-level priority, since they provide sustaining goods such as food and water, and residences are typically last. However, residential districts surrounding hospitals and emergency services centers are usually brought on-line with the adjacent facility since restoration normally proceeds neighborhood by neighborhood.

In addition, as has been noted above, a critical load may be defined in terms of a particular place or facility, not just a particular customer or group of customers.

5. Critical Energy Infrastructure Asset

U.S. energy systems include extensive networks of electric generating facilities and transmission lines, natural gas pipelines, oil refineries and pipelines, and coal mines and transportation systems.

Issued on February 20, 2003, the Federal Energy Regulatory Commission's (FERC) Final Rule in Order 630, concerning the protection of critical energy infrastructure information, defines critical infrastructure broadly to include “existing and proposed systems and assets, whether physical or virtual, the incapacity or destruction of which would negatively affect security, economic security, public health or safety, or any combination of those matters.”

An "asset" of an energy facility can be any person, equipment, material, information, installation, or activity that has a positive value to the facility [DOE 2002]. Key assets and high profile events are defined as individual targets whose attack—in worst-case scenarios—could result not only in large-scale human casualties and property destruction, but could also profoundly damage this Nation’s prestige, morale, and confidence. For example, key assets like nuclear power plants and dams may not be individually vital to the continuity of critical services at the national level, but a successful strike against such targets may result in a significant loss of life and property as well as long-term, adverse consequences to public health and safety.

Potential critical assets include people, equipment, material, information, installations, and activities that have a positive value to an organization or facility. "People" critical to energy production and delivery include energy facility executives and managers, security personnel, contractors and vendors, and field personnel. "Equipment" includes vehicles and other transportation equipment, maintenance equipment, operational equipment, security equipment, and computers and associated information technology equipment. "Material" includes tools, spare parts, and specialized supplies. "Information" includes employee records, security plans, asset lists, intellectual property, patents, engineering drawings and specifications, system capabilities and vulnerabilities, financial data, and operating, emergency, and contingency procedures [DOE 2002].

6. Critical Node

The facilities, systems, and functions that comprise our critical infrastructures are highly sophisticated and complex. They include human assets and physical and cyber systems that work together in processes that are highly interdependent. They also consist of key nodes that are essential to the operation of the critical infrastructures in which they function [White House 2003].

“Critical nodes” are those assets, systems, and functions that this Nation deems most “critical” in terms of national-level public health and safety, governance, economic and national security, and public confidence. Assets, systems, and functions that comprise infrastructure sectors are not uniformly “critical” in nature, particularly in a national or regional context.

7. Role of Criticality in Other Infrastructures

Both Congress and the Executive Branch have historically established criticality principles and policies in many of the critical infrastructure sectors. In some cases, the priorities are clearly written into law and regulatory policy. Regulations covering restoration requirements for the nation’s telecommunications infrastructure, for example, specifically define four levels of restoration criticality and incorporates infrastructure interdependencies.[18] Within each of the four restoration levels, regulators have negotiated sub-priorities that distinguish restoration for national defense as well as economic security purposes (e.g., electric utilities before gas utilities).

The Cold War dramatically influenced the national definition of criticality and the establishment of formal government requirements for public and private sector infrastructure restoration in the event of specific contingencies. In the telecommunications infrastructure, assured functionality for war mobilization, end-to-end communications for national leadership, and diplomatic communications vastly outweigh business and financial considerations. In contrast, banking regulators consistently prioritize economic and financial indicators in their calibration of criticality (economic

[18] See 47 CFR Part 211 (2003)

concerns are, of course, broader than this in nature). Similar requirements have not been present within the energy infrastructure.

For many infrastructure sectors, criticality policies are influenced by the awareness of the potential adverse impacts of disruptions on national stability, cross-infrastructure resilience, and the projection of power. Policy changes in at least two examples – telecommunications and financial services – offer important models for how the energy infrastructure might consider criticality, measure value, and integrate decisions into policies and programs.

The Financial and Banking Sector may offer the best model for the Energy Sector. Legislative, regulatory and policy activity since the 9/11 attacks indicate the following:

- National leaders have implemented criticality policies based on economic security and liquidity of the nation's financial markets;
- Criticality for private sector firms in the Financial and Banking Sector is a function of clear metrics that substantiate economic and financial principles, such as the total amount of transactions in a 24 hour period;
- Owners/operators of the most "critical" private sector infrastructure must undertake more stringent roles and responsibilities than owners and operators of non-critical assets;
- However, where firms are deemed critical, the government provides support, such as priority in restoration;
- Finally, criticality and restoration efforts and policies must seamlessly account for infrastructure interdependencies.

7.1. Telecommunications

Over the past 70 years, the Federal government has created a clear-cut philosophy for assessing criticality and managing response and restoration of essential telecommunication services.[19] Three major themes permeate telecommunications criticality issues and policies.

First, the core of the nation's approach to telecommunications criticality is steeped in Cold War fears and principles. Policies developed from the 1960s through the present administration, known as National Security & Emergency Preparedness ("NS/EP") telecommunications policies, were developed to ensure the nation's survival from a large-scale nuclear attack.[20] As listed in Figure 3 below, NS/EP policies from President

[19] The roots of national security communications first trace to the Cuban Missile Crisis in 1963. At the height of this national crisis, President Kennedy and his key advisors (both domestic and abroad) were unable to communicate adequately and reliably. Two factors, in particular, affected the national leadership's ability to communicate. First, federal agencies employed their own unique communications equipment and technologies, resulting in significant interoperability challenges. Second, communications roles, responsibilities, and jurisdictions spanned multiple agencies, creating questions about which agency would handle coordination, integration, and management of communications for the federal government. Consequently, President Kennedy formed the National Communications System to serve as the government's focal point for coordinating national-level communications.

Kennedy through the current Administration consistently and directly supported the national defense, national security, and emergency preparedness by ensuring a survivable and resilient national communications infrastructure during all contingencies. These objectives not only support end-to-end communications, but also project the strength of the telecommunications infrastructure, an important factor in deterring attacks in 1962 as well as today.

1. *Connectivity for the national leadership*
2. *Responsive support for operational control of the armed forces in all conflicts, including CBRN and support for military mobilization*
3. *Support for the vital functions of worldwide intelligence collection and diplomatic affairs*
4. *Continuity of government during and after man-made or terrorist event*
5. *Restoration and recovery of the nation during and after a man-made or terrorist event*
6. *Connectivity support for "critical infrastructures" -- although not referenced as such until after 9/11. Regulations include, for example, support for "public utility services."*
7. *Reliable and enduring threat assessment capability*

Sources: Communications Act of 1934; Presidential Decision Directives, Kennedy – Bush 43.

Figure 3. Criticality Principles for the Telecommunications Infrastructure.

Second, NS&EP telecommunications policies acknowledge the growing importance of critical infrastructure. Even before issuance of Presidential Decision Directive 63, which outlined a formal critical infrastructure policy for the first time, NS&EP telecommunications policy required prioritized restoration of certain infrastructures deemed essential: the National Airspace, utilities (including electric power), airports, and the healthcare infrastructure have consistently held the highest priority restoration status.[21]

Third, the National Communications System (NCS) has defined "essential services" for purposes of assigning priority status and restoration of telecommunications. According to NCS policies, telecommunications services are designated as essential where a disruption of "a few minutes to one day" could seriously affect the continued operations that support an NS/EP function. In addition, all NS/EP missions fall into one of five program categories: (A) National Security Leadership, (B) National Security Posture and U.S. Population Attack Warning, (C) Public Health, Safety, and Maintenance of Law and

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[20] The vast majority of the nation's criticality policies for telecommunications are memorialized in Executive Order 12472, prepared by the Reagan Administration shortly after the break-up of Bell Telephone. *Assignment of national security and emergency preparedness telecommunications functions*, Executive Order 12472 (April 5, 1984).

[21] Priority restoration policies are codified in 47 CFR § 211.5 ("Insure performance of critical logistic functions, public utility services, and administrative-military support functions; Inform key diplomatic posts of the situation and of U.S. intentions; Secure and disseminate urgent intelligence; Distribute essential food and other supplies critical to health; Provide for critical damage control functions; Provide for hospitalization; Continue critical Government functions; Provide transportation for the foregoing activities.")

Order, (D) Public Welfare and Maintenance of the National Economic Posture, and (E) Emergency.

The Administration is currently rethinking criticality of communications given the emphasis on Cold War pressures, as opposed to evolving terrorist threats. HSPD 7 specifically requires Federal agencies to re-examine how criticality principles – and ultimately, restoration activities – should change given the importance of critical infrastructure, the ability to connect national leaders, and the resilience of the communications infrastructure from attack.

Specifically, HSPD 7 requires the following (at § 36):

> The Assistant to the President for Homeland Security and the Assistant to the President for National Security Affairs will lead a national security and emergency preparedness communications policy review, with the heads of the appropriate Federal departments and agencies, related to convergence and next generation architecture. Within 6 months after the issuance of this directive, the Assistant to the President for Homeland Security and the Assistant to the President for National Security Affairs shall submit for my consideration any recommended changes to such policy.

That review is currently underway.

7.2. Financial and Banking

Four principles reveal the amount of thinking that has occurred since the 9/11 attacks and how the banking sector has characterized and implemented criticality and restoration policies among the nation's 20,000 financial institutions:

1. **Criticality principles are based on economic security and liquidity of the nation's financial markets – key statutory requirements for the banking regulators and oversight agencies.**

In contrast to criticality policies in the Telecommunications Sector, criticality philosophies, principles, and policies for the nation's Financial and Banking Sector are established largely to ensure the nation's financial and economic well-being. Regulators throughout the sector[22] set these policies.[23]

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[22] Shortly after the 9/11 attacks, the banking regulators formed the Financial and Banking Information Infrastructure Committee (FBIIC) to coordinate critical infrastructure issues across all of the relevant regulators. For example, the FBIIC sets policies for access to priority restoration services available via the National Communications System, such as Telecommunications Service Priority (TSP).

[23] Examples include priority restoration of telecommunications services for critical banks and "resilience" rules and expectations, such as additional security regulations for the most critical financial institutions. The nation's financial institutions, which total over 20,000 are highly regulated by a number of departments and agencies. In some cases, such as for insured national banks, at least two regulators oversee bank operations and set regulatory policies.

During the past 10 years, a single, sector-wide philosophy regarding criticality and restoration issues has dominated the Banking and Financial Sector. Since the 9/11 attacks, this philosophy has hardened around discrete policy objectives, including national liquidity, safety and soundness of financial institutions, and financial market resilience. In order to achieve these objectives, banking regulators have identified the importance of wholesale banking activities, such as payment, clearance, and settlement functions. These business functions, if disrupted, even for short periods of time, may result in the kinds of liquidity crises that occurred after the 9/11 World Trade Center attacks.

2. **For individual financial institutions, criticality is a function of clear metrics that substantiate *business and financial principles* – such as the total amount of transactions in a 24 hour period**.

The Financial and Banking Sector assesses criticality based on financial indicators linked to the nation's economic security. For instance, as indicated in the section on priorities below, critical financial services are defined [Federal Register 2002] as "large value networks that transmit a daily average aggregate value of at least $2 billion." Most recently, the Federal Reserve Board of Governors issued a revised policy for payments risk, which underscores the relative criticality of wholesale transactions large enough to warrant Federal government attention:

> This policy statement applies to privately operated multilateral settlement systems or arrangements with three or more participants that settle U.S. dollar payments, including but not limited to systems for the settlement of checks, automated clearing house (ACH) transfers, credit, debit, and other card transactions, large-value interbank transfers, or foreign exchange contracts involving the U.S. dollar where the aggregate gross value of payments is expected to exceed $5 billion on any day during the next 12 months [Federal Reserve Board 2005].

3. **Owners/operators of the most "critical" private sector infrastructure must undertake more stringent roles and responsibilities than owners and operators of non-critical assets.**

Criticality in the Financial and Banking Sector warrants additional regulator and supervisory scrutiny. Those private sector infrastructure owners whose components are deemed to be critical must undertake additional security roles and responsibilities. Examples include the following:

- **Must recover within same business day**: Firms that play significant roles in critical financial markets should maintain sufficient geographically dispersed resources, including staff, equipment and data to recover clearing and settlement activities within the business day on which a disruption occurs. The rapid resumption of critical financial markets requires that core clearing and settlement organizations are able to recover and resume within the business day the critical activities they perform that support the recovery of critical markets [Federal Reserve Board 2005].

- **Must implement geographic diversity**: Recovery of clearing and settlement activities within target times during a wide-scale disruption generally requires an appropriate level of geographic diversity between primary and back-up sites for back-office operations and data centers. Long-standing principles of business continuity planning, banking regulators argue, suggest that back-up arrangements should be as far away from the primary site as necessary to avoid being subject to the same set of risks as the primary location.

- **Must account for interdependencies**: Back-up sites should not rely on the same infrastructure components (e.g., transportation, telecommunications, water supply, and electric power) used by the primary site. Moreover, the operation of such sites should not be impaired by a wide-scale evacuation at or the inaccessibility of staff that service the primary site. The effectiveness of back-up arrangements in recovering from a wide-scale disruption should be confirmed through testing.

4. Where firms are deemed critical, the government offers priorities, such as priority restoration.

The government provides priority treatment to ensure that services are available to private sector firms which are deemed "critical." For instance, the banking regulators have memorialized criticality policies as part of a telecommunications restoration and priority program.

The Financial and Banking Information Infrastructure Committee (FBIIC) agencies have determined that to qualify for Telecommunications Service Priority (TSP) sponsorship, financial organizations and their service providers must support the performance of NS/EP functions necessary to maintain the national economic posture. FBIIC agencies will sponsor circuits that meet the criteria described below:[24]

- **Circuits Supporting Critical Payment System Participants (Depository Institutions, Financial Utilities):** The Federal Reserve Board originally established policies and procedures for sponsorship of organizations for priority provisioning and restoration of telecommunications services under the TSP program in 1993 (58 FR 38569, July 19, 1993). The Board recently updated its sponsorship policy and expanded its sponsorship criteria. Examples of circuits sponsored by the Federal Reserve include financial institution “large value networks that transmit a daily average aggregate value of at least $2 billion.” [Federal Register 2002]

[24] Sponsorship Process: The individual FBIIC agencies will contact appropriate financial organizations and service providers for which they are the primary regulator and inform them of the process to be followed to apply for TSP sponsorship. If a financial organization or service provider believes that one or more of its circuits qualify for TSP sponsorship, it should submit a sponsorship request in accordance with the process established by its primary regulator.

- **Circuits Supporting Key Securities & Derivatives Markets Participants**: In addition, the Securities and Exchange Commission and the Commodity Futures Trading Commission will sponsor circuits owned or leased by organizations that play key roles in the conduct or operation of the securities and derivatives markets and related clearance and settlement systems.

- **Circuits Supporting Other NS/EP Services:** The FBIIC agencies will also sponsor circuits owned or leased by organizations that do not meet the above sponsorship criteria if a disruption of those circuits could seriously affect operations that support the maintenance of the national economic posture.

These principles, as outlined, provide a practical model developed over many years which might be of use to the energy infrastructure in developing a similar strategy.

8. Restoration Objectives

In the event of a major outage, multiple objectives exist for the restoration process. These objectives could vary from one infrastructure sector to another or even within an individual infrastructure, as different infrastructure owners approach the restoration process differently. Restoration objectives fall in the general categories of safety, public health, public relations, and economics. In many cases, a customer in need of service restoration will fall under more than one category. The overall restoration objective is likely to include a combination of the individual objectives.

In general, the overriding principle in restoration is to protect the safety of both the general public and the employees of the affected company. Therefore, eliminating dangerous situations, such as a live, downed power line or a leaking natural gas line, is the first order of business. Another safety related restoration objective is restoring service to critical customers such as law enforcement and fire departments, airports, and communications facilities.

Another major objective is to minimize adverse health effects. This includes restoring service quickly to critical customers such as hospitals and health care facilities, emergency responders, and residential customers on life support. It may also include water and sewage treatment facilities.

Public relations objectives may include restoring service to the largest number of customers in the shortest period of time, minimizing adverse environmental impacts, and maximizing customer knowledge of the state of the restoration. Another potential public relations objective is to meet minimum regulatory standards.

Economic objectives include minimizing the cost of restoration activities, maximizing revenue to the service provider, and minimizing the lost activity and productivity of the customer. Customers with processes that are sensitive to time or temperature, especially perishable food processing and groceries, may be especially impacted economically by a prolonged outage.

9. Restoration Constraints

Energy infrastructure owners face a number of constraints when restoring services after a major outage. Constraints on restoration activities can be usefully subdivided into constraints on restoration actions, constraints on restoring particular assets, and constraints on restoring particular loads.

Constraints on restoration actions include the availability of parts and crews, access to system locations known to be out of service, knowing which specific assets are out of service, and knowing when it is safe for repair crews to begin repairs. The time required to assemble necessary resources to staff an emergency center and the time required to get crews to the repair location may present additional constraints. Legal, regulatory, and compliance requirements can also affect how restoration occurs. In some cases, for example, restoration crews must act in accordance with customer and service agreements; in other cases, agency regulatory requirements at the Federal as well as State and local levels impact corporate decision making.

Constraints on restoring particular assets include access requirements, knowledge that downstream points of transfer and consumption are safe, secure and ready to accept service, and the availability of the parts necessary to make repairs, or of spare equipment to replace damaged and unrepairable assets. Emergency services plans and protocols can also constrain the restoration of particular assets due to established obligations. Further, an established order of precedence for restoration requires that some critical loads be restored first even if a large residential population could be restored quickly with a minimum use of resources. The conditions under which restorations can proceed are bounded by agreements with neighboring utilities, control areas, applicable federal, state and local regulations and other authorities. Public safety and welfare always remains a central driver behind restoration.

Constraints on restoring particular loads include many of the constraint criteria listed above since, to some extent, critical loads define which assets are most critical for restoration of those loads. It is interesting to note that some loads are not economic to restore and would not be restored unless universal service requirements, laws or regulations required providers to do so. Small customers on the periphery of a service area, particularly small customers in thinly populated rural areas, would not receive service at all if not for applicable statutes and regulations that essentially codify cross subsidization from one customer to another, or one customer class to another class.

Due to just-in-time logistics, some companies have reduced their inventory of spare parts, a situation that could increase outage duration times. Increasing reliance on foreign suppliers for key replacement equipment and components (and potentially, installation assistance) can complicate and lengthen the repair and restoration process, and increase the risk of long-term disruptions. While the nation largely relies on imports for some types of energy infrastructure system equipment (e.g., large transformers), under current conditions ready access exists to a variety of stable foreign sources of supply that generally compete vigorously for U.S. market share.

10. Costs and Benefits to Consider in Restoration

In the event of a disaster, whether caused by man or nature, the restoration of services – power, gas, water, public health, police, and fire protection – has the obvious benefit of eliminating welfare losses experienced by the population as a result of the disaster. Usually during an emergency, little thought is given to economic considerations under the reasonable assumption that market activity is temporarily suspended while the emergency is being resolved. Yet considerable economic consideration is given to the restoration activity when planning for the emergency response. Both the likelihood of an emergency event and the likely magnitude of that event dictate what costs will be incurred for the staging of restoration, for the provision of spare parts, for the provision of emergency staff, etc. Economic considerations are much more evident in this planning process than in the emergency response. When disaster occurs, the emergency response is mobilized and responds according to the plan.

The economic consequences of a disaster can be separated into two categories: the economic costs of the disaster itself, and the economic costs of the restoration of services as a result of the disaster. It is useful to separate these two components because some consequences of the disaster cannot be restored: lives lost, sales lost, etc. The total economic impact from the potential disruption of a critical energy infrastructure asset typically considers the following factors:

- Time of year (and associated weather);
- Degree of disruption;
- Availability of backup systems;
- Volume handled by the asset (i.e., throughput, capacity, deliverability);
- Cost of repair/replacement (structures and vehicles);
- Cargo loss and property damage;
- Time to repair;
- Disruption of commerce;
- Costs of delay;
- Delays to general public;
- Cost of rerouting/diversions/alternate modes;
- Response costs – material and labor resources, communications, rescue activities, and evacuation of threatened population;
- Cleanup costs (debris) for damaged structures and vehicles; and
- Cleanup costs (hazmat) for hazardous materials removal and decontamination.

Determining the full cost of a disruption requires help and support from various groups and departments within the affected company. For incidents involving injuries or deaths, the legal department, risk management (usually in the finance department), and certainly senior management support is required over an extended period of time to ultimately determine the full costs involved.

10.1. Direct Costs

Direct costs include the cost of installed equipment, material, and labor directly involved in the physical reconstruction activities.[25] Discussion of direct restoration costs begins with mobilization, then turns to the three basics – structure, equipment, and infrastructure. A later section, Indirect Costs, will consider other costs such as lost output, lost lives, and the loss that may occur as a result permanently altered perceptions about the viability and safety of an area. Another cost to be considered, though difficult to quantify, is the cost of replacing temporary fixes with permanent installations.

10.1.1. Mobilization Costs

Before restoration activities begin, mobilization of emergency response facilities and personnel must be undertaken, following the mobilization plan which includes an assessment of the hazards to which the crews will be exposed and the extent of the damage requiring restoration. The extent of the damage and the existing hazards influence restoration priorities (e.g., downed power lines to be de-energized, fires to be put out, and roadways to be cleared). If current crews are inadequate to the restoration task, additional crews need to be summoned from outside the disaster areas. All of these activities incur costs that are borne by the providers of the services within the emergency areas or by emergency funds from Federal sources.

[25] A more detailed definition is provided by 18 CFR Chapter 1, at http://www.ferc.gov/legal/ferc-regs/acct-matts/usofa/gas/gas-usoa-part-201.pdf

Mobilization costs are generally assumed to be a percentage of the project's direct cost and are applied to both the prime contractor and subcontractors. The individual components of mobilization are as follows:

- Personnel Mobilization is the cost of mobilizing a contractor's personnel to the project site and includes moving in personnel, setting up the site, holding pre-installation meetings, and orientation and training of personnel, if necessary;
- Equipment Mobilization is the cost of mobilizing a contractor's equipment to the project site and includes moving and setting up equipment used by a contractor for the duration of the project, such as cranes and pipe-laying equipment; and
- Demobilization is the cost of breaking down and removing all temporary facilities and removing equipment from the project site.

10.1.2. Replacement of Lost Structures

Structures destroyed or damaged in a disaster take time to repair or replace. For personal residences, insurance and Federal emergency aid will partially cover these costs; insurance coverage provides a reasonable estimate of the value of the property lost. Dislocation associated with damaged residences is likewise part of the costs. For businesses, insurance and Federal emergency aid will also partially cover these costs. Estimation of the true value of the losses and reconstruction costs can only be made with acknowledged uncertainty. Payments made by either relief agencies or insurance firms are an indication of the costs of damage, but reconstruction costs are usually higher than insured costs. Reconstruction is a burden on local labor markets after a disaster, with far more construction needed than the available workforce can achieve. Moreover, the supply chain for material used for reconstruction is not functioning as it would normally. In the case of hurricanes and floods (and in other circumstances), a moral hazard[26] issue arises because certain areas are more prone to these events than other sites. To the extent that insurance rates reflect this higher probability of occurrence, then the moral hazard issue is mitigated. To the extent that emergency aid substitutes for insurance, moral hazard is an issue.

10.1.3. Equipment Replacement Cost

Equipment replacement cost is the cost of replacing or repairing damaged equipment. Many of the same issues arise with replacement costs for equipment as with structures. One major difference is that equipment is normally not reconstructed on the spot; it either has to be replaced or rebuilt by qualified producers. With damage to structures and infrastructure, removal and transport of either damaged or new equipment is often problematic. As with structures, damage is often covered by insurance, but replacement costs are a better measure of the lost opportunity.

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[26] Moral hazard is the name given to the risk that one party to a contract can change their behavior to the detriment of the other party once the contract has been concluded. For example, the existence and expectation of federal disaster aid will reduce flood prevention or relocation to less risky locations, and encourage construction (or reconstruction) in floodplains [Wikipedia, 2005].

This assumption is confirmed by data on the U.S. petroleum refining industry. Losses in the refinery industry have continued to increase over the last few years, and the causes highlight the aging facilities in this category. A significant number of larger losses (over $10,000,000) have been caused by piping failures or piping leaks, leading to fires and/or explosions. Weather-related incidents played a major role in two losses that were each over $200,000,000 [Marsh Risk Consulting Practice 2003].

Marsh Risk Consulting Practice (2003) provides one of the more concise sources of reference for large losses within the oil, petrochemical and gas industries over the last thirty years. It provides information such as the cost of major disasters and the amount of time to repair and restore. Information from this reference associated with the loss of a crude distillation tower is provided in Table 1.

Similar equipment cost issues surround major elements of the energy sector, including turbines and substation transformers (in the electric power sector) and compressor stations (in the natural gas sector). Direct equipment replacement costs, however, are relevant for all replaced/repaired equipment, not only those items with high costs cited here.

Table 1. Refinery Incident Data (Marsh 2003).

Location	Unit(s) Affected	Capacity (Kbbl/d)	Date Down	Cause	"Lost Time" (days)	Incident Cost ($M)	Business Interruption Cost ($M)
Lemont, IL	Crude unit	158,650	8/14/01	Fire	180	36	NA
Wood River, IL	Crude unit	286,400	4/28/01	Fire	14	68	NA
Thessaloniki, Greece	Crude unit	66,500	2/19/99	Fire/ Explosion	NA	43	NA
Beaumont, TX	Crude unit	310,000	11/3/91	Fire	30	18	NA
Port Arthur, TX	Crude unit	235,000	1/12/91	Fire	180	31	76
Note: "NA" = not available							

10.1.4. Infrastructure Construction/Repair Costs

Repair costs go well beyond those cited in the previous section. In addition to the cost of the equipment specified, the repair is also likely to include property damage (either directly from the disruptive event, or indirectly as it is necessitated for proper repair). This section addresses these infrastructure construction and repair costs.

Property damage/loss includes, but is not limited to, costs due to property damage to the operator's facilities and to the property of others; lost product; restoration of service; facility repair and replacement; and environmental cleanup and damage. Facility repair, replacement, or change that is not related to the incident but is performed by the operator as a matter of convenience (for example, to take advantage of access to facilities unearthed because of the incident) is not to be included.

As an example, in cases when work must be done beneath paving of some type, these surfaces must first be broken and removed. This occurs during natural gas pipeline leak repair in urban and suburban areas. Leaks caused by third-party damage are of special concern because the pipe is usually ruptured and the safety hazard is greater. In most cases a leaking plastic main, regardless of size, is repaired rather than replaced. In contrast, a leaking residential steel service line is often completely replaced [Biederman 2002].

When infrastructure disruptions occur (as the result of direct or indirect damage, as described above), the roles and responsibilities of local, state, and federal governments often conflict. These conflicts of interest regarding jurisdiction can impede timely restoration of service.

10.2. Indirect Costs

In addition to the direct costs outlined above, indirect costs need consideration. These indirect costs include all required costs that do not become a final part of the installed repair, and may include, but are not limited to, field administration, direct supervision, capital tools, startup costs, contractor's fees, insurance, and taxes. Indirect costs also include temporary construction services, maintenance of tools and equipment, materials handling, supplies, equipment rental and/or purchase, fuels, and lubricants. Other factors, such as the cost of replacing temporary fixes, legal liabilities, lost production or abandoned purchases, and lost lives, also serve as indirect costs and need to be considered as part of the cost of the emergency, though they may not be direct costs of restoration.

Indirect costs can vary from 40% to 100% of the direct field labor cost, and vary depending on individual company policy for what is included or excluded. The most common factors are 60% to 75% of the total field labor cost.

10.2.1. Legal Liabilities

An emergency is likely to give rise to legal costs and potential liabilities. Liabilities as a result of the emergency can arise from contracts in place at the time of the emergency (e.g., insurance policies), negligence on the part of a service provider, or as a result of statutes that imply a responsibility for emergency response or restitution in the event of an emergency.

10.2.2. Lost Output and Abandoned Purchases

Commercial activity during an emergency is typically curtailed, the extent of which is dictated by the type of emergency. In the event of a loss of power, most commercial activities cease unless they can be conducted with emergency power or without power (security concerns and liability concerns dictate that most stores close when power is interrupted). Gas curtailments can force facilities to close for environmental or operational concerns. Massive power failures, such as occurred during August 2003, may have created lost sales for commercial establishments, industrial firms, and unmet energy demand in the billions of dollars.

Estimates of power outage costs as a result of lost sales are available from various sources. The New York blackout in 1977 was estimated to have cost about $345 million, with direct costs about $56 million. Of those direct costs, only about $12 million were outlays by Consolidated Edison for restoration and overtime costs. The other direct costs were for incremental wage costs for other public services, banking and security costs, food spoilage, lost wages, and equipment damage. These costs pale in comparison to the lost business, replacement capital equipment purchases, incremental insurance costs, assistance programs and other costs, that amounted to over $290 million [Balducci et al., 2002].[27]

Even in inflation-adjusted dollars, the 1977 New York power failure was minor in comparison to the power failure on the East Coast in August 14, 2003. Cascading power failure eventually left more than 50 million people without power in eight U.S. states and two Canadian provinces, shutting down 100 power plants, 12 airports, and leaving 350,000 commuters stranded in New York subways. The estimated costs for this event range from $1.5 billion to $6 billion.

10.2.3. Lost Lives

The 2004 hurricanes caused a number of deaths. While it is difficult to place a dollar value on loss of life, courts do it as a matter of record. The tragedy that families suffer from loss of life during emergencies is without monetary equivalent.

10.2.4. Perception Impact as a Result of the Emergency

When Hurricane Iniki hit Kauai in the September 1992, the devastation was on the order of half a billion dollars. Twenty-foot waves devastated property in Poipu on the south coast of the island, including several resort hotels. Even 12 years later, these hotels have not been restored. The perception that the south coast of Kauai is a danger zone may preclude any such resort development in the future, even though the probability of such an event occurring in the near future is small.

10.3. Mechanisms to Recover Restoration Costs

The National Research Council released a report in 2002 titled "Making the Nation Safer: The Role of Science and Technology in Countering Terrorism." This report makes the following recommendation in the Chapter on Energy:

> "Recommendation 6.7: Both FERC and the State utility commissions (perhaps through the National Association of Regulatory Utility Commissioners) should allow certain counter terrorism costs -- specifically, for actions taken to reduce the vulnerability of critical equipment within an electric utility's operation and to speed recovery

[27] All figures are reported in 1996 dollars.

> following an attack -- to be included in the rates that the utility can charge for its services." [National Research Council 2002]

Similarly, the National Association of Regulatory Utility Commissioners (NARUC) argues that States should approve appropriate applications by electric and gas companies subject to their jurisdiction to recover prudently incurred costs necessary to further safeguard the reliability and security of our energy supply and delivery infrastructure [NARUC 2003].

A LDC can petition a PUC for a temporary rate increase but must demonstrate that at least one of the following has occurred or will occur prior to the time that permanent rates are expected to be approved or in effect:

- a loss of revenues or an increase in expenses caused by factors outside the control of the utility such as a Force Majeure[28] or catastrophic outage (i.e., possible terrorist attack) which has resulted in or will result in an inability to render service in compliance with the standards of service prescribed for the particular utility; or
- an inability to raise needed capital at a reasonable cost

If these cannot be demonstrated, the LDC would notify the PUC when a disruption has occurred, keep it informed of the costs to restore service, and if necessary, ask for an increase in the permanent rates when the time for their approval arrives.

Restoration costs from a catastrophic disruption will ultimately be paid by consumers, through increased rates. Requirements vary between distribution and transmission companies in the natural gas infrastructure. In the event of a catastrophic disruption, transmission pipeline companies work to maximize the federal funding available to cover these costs and/or to ensure the availability of methods of cost recovery.

FERC's responsibilities include the regulation of rates and practices of oil pipeline companies engaged in interstate transportation; regulation of pipeline, storage, and liquefied natural gas facility construction; and regulation of natural gas transportation in interstate commerce [FERC 2004]. The mechanisms to recover costs associated with interstate pipeline restoration are outlined in each pipeline's tariff.

FERC has no jurisdiction over construction or maintenance of production wells, oil pipelines, refineries, or storage facilities. Petroleum refineries operate in a competitive environment, where the costs of a catastrophic disruption cannot directly be passed on to its customers by regulatory oversight. As stated above, the replacement costs for a large

[28] In the natural gas industry, the term "Force Majeure" means any act of God, war, civil insurrection or disobedience, acts of public enemy, strikes, lockouts, or other industrial disturbances, accidents, wars, blockades, insurrections, riots, epidemics, landslides, lightning, earthquakes, explosions, fires, storms, floods, washouts, arrests and restraints of governments and people, civil disturbances, breakage or accidents to machinery or lines of pipe, the necessity for making repairs to or alterations of machinery or lines of pipe, freezing of lines of pipe, inability to obtain materials, supplies, permits or labor, or other cause whether of the kind enumerated or otherwise which is beyond the control of any applicable pipeline or shipper.

Gulf Coast refinery could exceed one billion dollars. This cost may cause the refinery owner to consider shuttering of the entire disrupted facility. More likely, a business decision will be made by the refinery owner as to whether to rebuild or consider location abandonment as an option, or to simply rebuild a portion of the entire refinery. A similar case can be made for offshore platforms, which may cost on the order of one hundred million dollars or more.

10.4. Benefits

Comparing costs with benefits facilitates good decision-making. Other sections of this report have discussed the costs and procedures involved in restoring energy services in the event of a disruption. This section of the report discusses the benefits associated with components of an energy infrastructure. In particular, the section addresses two questions:

1. Weak links. Under normal operating conditions, how might components be ranked to reflect the vulnerabilities they represent, especially for valuable supply chains?
2. Sweet spots. When multiple components have failed, how might they be ranked from a systems perspective to reflect their relative value and aid their prioritization for restoration?

In discussing the value of a component of an energy infrastructure, three points seem especially important.

1. Substitution. The availability of a substitute for something – whatever the form – means that its failure may not result in catastrophic consequences.
2. Valuation. It is often feasible to estimate the value of the losses associated with a failure, such as lost production, sales, or even comfort. Valuation of some losses, such as deaths and injuries, are both difficult and controversial.
3. Prioritization. Applying these concepts of substitutes and valuation can address the practical problem of prioritizing a list of "critical" elements of an energy infrastructure.

On a purely economic basis, the priority of restoration would be driven by welfare, i.e., who benefits most. From a practical perspective it is not possible to completely direct restoration of services to specific end users. More likely, only service regions that include a mix of different classes of consumers can be targeted. Economic approaches – especially respecting the value and availability of substitutes in the event of a disruption – play a vital role in determining the degree to which elements of the energy infrastructure are critical and in assessing plans and practices for restoration.

10.4.1. Substitution

When the lights are on, many parts of the electricity system must be working fairly well – from the coal seam to the filament in the light bulb. The failure of one or more parts would force the system into some substitute arrangement. This section considers substitution in the context of assessing “criticality.” Although the examples given are mainly electric, the concepts discussed here apply in other infrastructures as well.

Substitutes in production. In energy production processes, there are typically many ways to get the job done. When one way becomes unavailable due to component failure, managers consider alternatives. If a natural gas pipeline fails, it may be possible to deliver additional gas via another pipeline or to draw from inventories. If an electricity generating unit fails, it may be possible to generate and transmit additional electricity from other plants. Plentiful local inventories of natural gas and oil can substitute in the event of transmission pipeline failure; lack of storage sets electricity apart here.

Substitutes in consumption. If the lights actually go out, residential consumers consider alternatives including candles, flashlights, sleep, back-up generation, neighbors, hotels and leaving town. Commercial electricity consumers consider back-up generation, taking a holiday and doing business in the dark. Consumers for whom uninterrupted energy is vital (hospitals, for example) often have ready substitutes. When natural gas delivery fails, oil, electricity, wood, and alternate venues may be substitutes. When gasoline supplies become tight, consumers may carpool, telecommute, delay vacation plans, etc.

Variability in substitution. The options for substitution can change. In periods of peak consumption, for example, substitution options may be limited. Substitution options can be dependent on many conditions including interoperability (e.g., does a natural gas-fired gas turbine have the ability to consume light oils), season, other outages or failures, and inventories.

Substitution and criticality. The question, ‘What are the alternatives?’, serves as an important starting point in assessing the degree of criticality of an energy infrastructure component. If acceptable alternatives for a component are likely to be available under all conditions, it seems reasonable that that component should not be considered critical. A component being “critical” would seem to require that good substitutes for it would not be expected to be available in important situations in the event that commodity deliveries are curtailed. How poor such substitutes are produces a meaningful index of “criticality." The options and availability for substitution are important factors in assessment of component criticality.

10.4.2. Valuation

Techniques are available for estimating the lost value associated with energy disruptions. As discussed elsewhere in this report, the core concept is *consumer surplus*. The main idea is that most consumers of a product place a higher value on their consumption of the product than the price they have to pay to consume it. Therefore, the loss imposed by a disruption is valued more highly than simply the price paid. The difference can be estimated by using statistical demand systems, assessing direct costs (lost productivity, reduced sales, damaged product) or via non-market valuation techniques including measuring contingent valuation (willingness to pay).

Studies typically find wide differences among energy consumers in the lost value associated with a disruption. This wide variation in valuation reflects many differences in energy consumers and their circumstances, including, especially, the substitutes available to them. Service disruptions that might compromise health or safety are an important part of the variability in valuation; the impact of such outages is often mitigated by the availability of substitutes. For example, hospitals are usually required to have back-up power.

Results from valuation studies can be controversial. What is not controversial is the observation that the value of an energy loss to different customers varies and that there are methods to estimate these relative magnitudes. Such valuations could play a role assessing criticality: consumers with the highest valuations might be regarded as more "critical." As mentioned above, direct economic impact is not the lone metric in determining valuation.

All elements of restoration have an economic cost (dollar valuation) associated with them. Some costs are borne by the energy infrastructure provider and others are incurred by the customer (or society) due to the disruption. The latter costs are properly accounted as un-recovered benefits of the restoration. The most obvious of these un-recovered benefits are outcomes of a disruption that are catastrophic, e.g., major environmental disasters and loss of life.

Disruptions of energy services may result in failures of other systems needed to maintain environment, safety and health (ES&H). High benefits are associated with these types of activities, since they cannot be temporally or spatially substituted. When the demand is completely inelastic, the benefit is unbounded. While this may be the best definition of critical service, when a restoration cannot be effected in time to avoid major ES&H outcomes, the potential cost of environmental cleanup or the cost of life (value of judgment) in wrongful death resulting from a disruption may be considered in the business case for restoration (and preventative) activities.

Appropriate integration of risk assessment by the energy infrastructure could mean considering high impact, low-probability (HILP) events within an insurance component of the business. In effect, insurance markets integrate these HILP events into the business case for the energy provider. In the absence of effective insurance markets for these HILP events, political/regulatory intervention may be needed (and has been invoked). This is an important concept, given the high degree of self-insurance existent in the energy infrastructure.

10.4.3. Prioritization

Given a list of components of an energy infrastructure, how can we determine which are "critical"? That is, which ones should get priority (for hardening or back-up redundancy) because their loss would have larger consequences? That is, where are special points of vulnerability – the weaker links? An expected dearth of substitutes (either in production or consumption) suggests a weak link. Having consumers who value the energy especially highly relative to the substitute imposed by an outage also indicate a weak link.

Two important observations are worth noting. The first is that because electricity cannot be stored meaningfully – so that inventories cannot serve as a substitute in the event of disruption – components of the electricity infrastructure are likely to be higher up the "criticality" list. This is reinforced by redundant uses for some electric facilities (e.g., large hydroelectric dams often serve as highways, water storage and dispensation facilities, and national icons). The second observation is that because of redundancies, back-ups, work-arounds, and the ever-changing condition of the rest of an infrastructure, the impact of the disruption of any component is not obvious.

In the event of a disruption involving many components of an energy infrastructure, how can we determine which ones should get priority for restoration because their ongoing disruption has larger societal consequences? That is, where are the sweet spots? Valuation studies – perhaps specialized for a specific energy system and for the locations of facilities – can indicate which consumers have higher valuations and the degree of difference. This information can be used to inform restoration protocols.

One common approach is to restore electric power to "as many people as possible as quickly as possible." This indicates a priority placed on maintaining public health and safety. Such a practice may not be consistent with the ideas presented here. Would people prefer that their place of work or their home be restored first? That question is not answered here – either in general or for any particular infrastructure or locale. Instead, it is suggested that this is an important question, which is amenable to study, and that the results could be incorporated into restoration protocols.

The private sector owns and maintains the majority of the energy infrastructure in this Nation. An individual company's list of critical assets and the order by which they are restored (prioritization) may differ from that developed by the State in which the assets are located and by the Federal Government. This distinction is important in understanding how economics can be applied by each of these stakeholders in the energy infrastructure.

11. Stakeholder Roles in Restoration Prioritization and Economic Decision-Making

The roles of the infrastructure owner, the consumer, and the local, State, and Federal regulator are so intertwined that separating the discussion of their roles is impractical.

11.1. Infrastructure Owners, Consumers and State Regulators

Since the circumstances of each event causing an outage are unique, there are no hard and fast rules for outage restoration. Different sectors of the energy infrastructure – and different utilities within the electric power sector – may have different priorities as to which loads to restore first. Despite outage restoration being described as more of an art than a science, most outage restoration will follow a general pattern.

For an electric utility, the first steps in outage restoration are system evaluation and damage assessment to determine the outaged area and the amount and location of damaged equipment. This is often followed by the restoration of power to critical loads. Since critical loads generally have on-site emergency generation facilities, some utilities will give a higher priority to restoring services to the largest number of customers in the shortest period of time. If the outage lasts for an extended period of time, critical loads will be given a higher priority to avoid putting excessive stress on their emergency generators. During large, extended outages, periodic conference calls are held among affected utilities and their restoration teams to discuss the status of the restoration effort and to reprioritize.

Other factors that can affect restoration priorities include public perception, customer satisfaction and feedback from regulators. While these factors may have some impact during an outage (the squeaky wheel may indeed get the grease), they generally have more effect post-mortem.

Generally, large or critical customers have a specific account representative assigned to them. During an outage, the customer and the account representative are in contact to assess the needs of that customer. If a critical customer needs restoration as soon as possible, the customer can be given a higher priority.

A similar situation exists in the natural gas industry. In times when gas supplies are "tight," equipment fails, or other disruption events occur, several dilemmas are presented to transmission and distribution companies. Because transmission and distribution companies do not own the gas being transported, they cannot make unilateral decisions regarding allocation of short supplies. When a customer's contractual supplier is unable to deliver, a question arises as to which company will provide backup supplies. Regulatory procedures have not fully resolved this issue. Under extreme emergency conditions, however, issues that involve the protection of public health and safety take precedence over contractual issues.

Load shedding of the end user by a natural gas LDC starts with large industrial and electrical generating facilities with alternate fuel backup, followed by large industrial, commercial, and electrical generating facilities without alternate fuel backup; continues with medium to small commercial facilities, schools, and other businesses. Only once each of these customer groups are shed will a natural gas LDC shed hospitals, nursing homes, essential services providers, and residential customers. In almost all cases, residential customers are the last affected group of customers. When natural gas supply is restored, the order is reversed.

State regulators rarely take direct action during an outage. The affected utility will keep the regulators informed of the status of the outage and restoration efforts; regulatory personnel may even sit in on the utility's conference calls during an extended outage.

After the outage has been restored, the regulators may wish to review the events leading up to the outage and the restoration process. If the regulators believe that a problem exists, they may request the utility to address the problem either to prevent further outages or to facilitate recovery.

Economic factors generally do not have an overt impact on restoration efforts. That is, utilities do not usually consider lost revenue or the costs of repairing equipment during an outage. They do make economic decisions on a more indirect basis, such as trying to use repair crews in the most efficient manner possible. Also, economic factors tend to have more of an impact post-mortem, as the utility reviews the outage restoration process and considers ways in which it could have been done more economically.

The (partial) regulation that exists for both the electric power and natural gas sectors does not exist in the POL sector, where market demands play a more significant role. In the event of a large-scale disruption (such as the shutdown of petroleum refineries due to fires and/or explosions), the price of gasoline, for example, could increase to a level where the costs of imported gasoline would become competitive. Constraints on the petroleum product supply system (such as rising demand and the closure of marginal refineries) can result in large regional differences in the price of gasoline, jet fuel, and other refined petroleum products. Moreover, millions of barrels of gasoline are stored in numerous locations within the U.S. to act as a "cushion" against a short-term disruption in the normal distribution pattern.

11.2. Governing Authorities

A wide variety of entities provide governance over the process of restoration, whether it be in the establishment of preconditions for initiating restoration of service, through general oversight of the day-to-day operations of infrastructure sectors, or as the result of specifics associated with the disruptive event.

Day-to-day operations of energy sector businesses are subject to controls at the national level, whether defined by federal agencies, such as the Federal Energy Regulatory Commission, or by industry-voluntary agencies, such as the North American Electric Reliability Council. Compliance with the rules established by these entities includes planning and action on response requirements at the occurrence of a disruptive event (including reporting requirements) as well as planning and coordination efforts that can aid in the response to particular disruptions.

The occurrence of a disruptive event brings with it event-specific responses that will vary based on conditions, location, and impacts to the surrounding infrastructure and to the general public. Events with a suspicious cause will incorporate a response from law enforcement, potentially including local police and sheriff's departments up to federal law enforcement agencies. The importance of preserving a potential crime scene will be carefully weighed against the commencement of restorative action. Location of a disruptive event can introduce unexpected externalities to the restorative effort as well. For example, a pipeline disruption in the Western United States has a substantial risk of occurring on federal lands or on Native American reservations. This can, in turn, lead to a one-day delay in the commencement of restoration activities until permitting can be obtained through the Bureau of Land Management or the United States Department of the Interior, Bureau of Indian Affairs.

11.3. Other Regulatory Agencies

Regulatory agencies such as the Environmental Protection Agency, United States Coast Guard, and the Department of Labor Occupational Safety and Health Administration have the potential to impose constraints on the restoration process and on prioritization decision making. These impacts are necessary, in the cases of the agencies cited above, for the preservation of the well-being of the environment (and, in turn, its economic usefulness from a livability and tourism perspective), and the workplace safety of employees in the energy infrastructures involved in restorative actions (and in turn, the economic power of a working employee), respectively.

11.4. The Department of Energy

The United States Department of Energy has several different, yet interconnected roles that can have an impact in restoration prioritization and decision making. DOE is a consumer of energy and as such, has an interest in the prioritization of those demands which are critical to the successful meeting of DOE's overarching mission, "to advance the national, economic and energy security of the United States; to promote scientific and technological innovation in support of that mission; and to ensure the environmental cleanup of the national nuclear weapons complex," [DOE 2003] and in support of the four strategic goals toward achieving this mission:

- Defense Strategic Goal: To protect our national security by applying advanced science and nuclear technology to the Nation's defense.
- Energy Strategic Goal: To protect our national and economic security by promoting a diverse supply and delivery of reliable, affordable, and environmentally sound energy.
- Science Strategic Goal: To protect our national and economic security by providing world-class scientific research capacity and advancing scientific knowledge.
- Environment Strategic Goal: To protect the environment by providing a responsible resolution to the environmental legacy of the Cold War and by providing for the permanent disposal of the Nation's high-level radioactive waste.

DOE is also a producer/developer of technologies to support national and energy security, and (as mentioned earlier in this document) serves as the SSA for the energy sector under HSPD 7. To these ends, support of basic and applied research and investigation into efforts such as this document, provide support to DOE strategic goals, to the surety of the energy infrastructure, and to those sectors of the economy and national interest which depend on reliable operation of the energy infrastructure.

11.5. Other Federal Agencies

One can essentially narrow the role of other federal agencies to being consumers of the energy infrastructure product in support of their respective missions.[29] These agencies will take actions in support of their importance in the restoration cycle, locally, regionally, and nationally. These agencies may have a coordinated, agency-wide stake in the restoration of energy services. In particular, these agencies have in the past invested time and energy in developing prioritization of their assets in support of their respective missions. These previous prioritization efforts could in fact be leveraged to support an institutional understanding of the role such end users play in current prioritization methodologies relative to other (known) priority customers.

12. Suggestions for Further Research

12.1. Application of Principles Developed by Other Infrastructures

Other infrastructures, such as telecommunications and banking and finance, have developed and implemented regulations and policies for day-to-day business dealings based upon consensus principles for determining criticality, as well as measures for HSPD 7 related metrics of national well-being (such as Public Trust and Confidence in Government). These policies take a broader view than the service territory-centric view of the typical energy services company, whose focus is on maintaining reliable supply of energy to their customers.

The telecommunications and banking and finance infrastructures have developed these principles and metrics based on consultation across their respective industries and in concert with experts from other infrastructure sectors. A similar effort within the sectors of the energy infrastructure, possibly utilizing the metrics and methods followed by these other infrastructures as a template, is highly recommended. These parallel efforts would be of particular benefit for high consequence events which span multiple interdependent infrastructures. Understanding the interdependencies of multiple critical infrastructures is necessary to build the proper metrics, methods, and policies to be followed within the energy industry with the objective of minimizing costs to all affected parties.

12.2. Application of Economics to Decision-Making under Uncertainty

A fundamental premise of achieving optimal economic efficiency is acquiring perfect information. Perfect information, as a practical matter, is a near impossibility. As the quality of information decreases, the likelihood of realizing an economically efficient use

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[29] There are, however, some Federal agencies that do have substantial generation capability (including Department of Defense vessels, under the Secretary of the Navy, which can be connected to the grid while at port and can provide substantial support to the grid) and other supporting resources (including deployed National Guard troops in support of security efforts, and Army Corps of Engineers forces in support of infrastructure restoration),

of scarce resources decreases. However, economics can help guide restoration decisions with fuzzy information, including those that require active managers to accept the possibility of doing nothing until the extent of the problem is known. Economic theory is well developed for decision making under uncertainty.

Events such as the ice storms that affected eastern Canada in January 1998 and the southern Appalachians in December 2002 show the role uncertainty plays in decision making. In these types of events the restoration team might not know at any point in time precisely which elements of the system are damaged (and the degree to which those elements are damaged), what is the source of the system failure (load, generation or transmission), and what points of the system are accessible to initiate repairs. During a freeze/thaw cycle which can go on for days, restoration is especially difficult.

12.3. Application of Computer Models that Integrate Economics

One way of quantifying economic impacts caused by service disruptions is through the adaptation and application of existing computer models. Both the Department of Energy and the Department of Homeland Security have made significant investment over the last decade in critical infrastructure modeling in general, and in energy systems modeling in particular. These models integrate both the physical performance of systems and the economic consequence of disruptions. An example of such a modeling effort is the Critical Infrastructure Protection Decision Support System, under development by researchers at Los Alamos National Laboratory, Sandia National Laboratories, and Argonne National Laboratory. The effort, funded by the Department of Homeland Security's Science and Technology Directorate, is designed around the construction of integrated systems models at both metropolitan and regional levels to detail interdependencies within and across each of the HSPD 7 infrastructures, and to provide useful indicators of the performance of infrastructure and the nation's economy in response to disruptive events.

Further examination is required to gauge the usefulness of this and other tools to provide an objective examination of problems facing energy infrastructure decision makers, both to guide restoration planning and to aid in prioritization (before and during an event).

12.4. Application of Economic Principles to Low Probability, High Consequence Events and Interdependencies Mitigation

Energy companies generally have a risk management program that includes hazard identification, hazard evaluation, consequence analysis, risk assessment, prevention measures, mitigation measures, risk reduction, and risk acceptance. Risk management programs typically focus on a range of threats, including an outage at an infrastructure component, caused by inadvertent human error that causes minimal infrastructure disruption, to natural disasters and other physical events.

Although economics tools and constructs are implicitly or explicitly embedded in almost every step of a restoration process, economics has been underutilized for analyzing potential response mechanisms for events that have not been historically encountered and are typically outside of an energy company's risk management program. This includes events of significant duration or magnitude, particularly those events with a low probability of occurrence (such as a societal change that threatens an entire infrastructure or widespread emergencies).

Economics can also play a significant role in guiding restoration decisions affecting multiple infrastructures. The interdependent nature of the nation's infrastructure is most clearly shown in these types of events. Figure 4, for example, shows the impact to dependent infrastructures and economic sectors as the result of the August 14, 2003 blackout. Understanding the economic characteristics of these infrastructure assets and their impact on public health and welfare can provide guidance for very complicated (and possibly counterintuitive) restoration decisions.

The energy infrastructure would benefit from regionally integrated models and/or training tools that estimate the economic consequences resulting from disruptions of significant duration or magnitude (including infrastructure interdependencies) while appropriately taking into consideration event probability. This can be particularly useful if it incorporates uncertainty (as described above). Results of such an analysis can provide system operators an opportunity to review the costs incurred in the restoration process, as well as system redundancy and reinforcement that can minimize disruption impacts and improve overall system reliability against the average disruption cost.

12.5. Application of Market Principles to Prioritization

In the United States, wholesale energy markets in many instances permit prices to vary by time and location. These regional price variations create a temporal price topology that should reflect the marginal cost to meet demand to each individual location on the supply network. Assuming that such systems remain intact following a sudden network reconfiguration (such as loss of a critical node), the resultant real-time price signals could permit economically efficient allocation of available supplies, assuming market transparency, consumer knowledge, and an ability of consumers to benefit from responses to price signals. Markets could be modified to reflect "must serve" consumers (such as hospitals and other similar critical loads), in the same way that the supply side of said markets includes "reliability must run" producers (who exist in some market structures and are required to provide service no matter the cost or expected revenue so as to maintain system reliability).

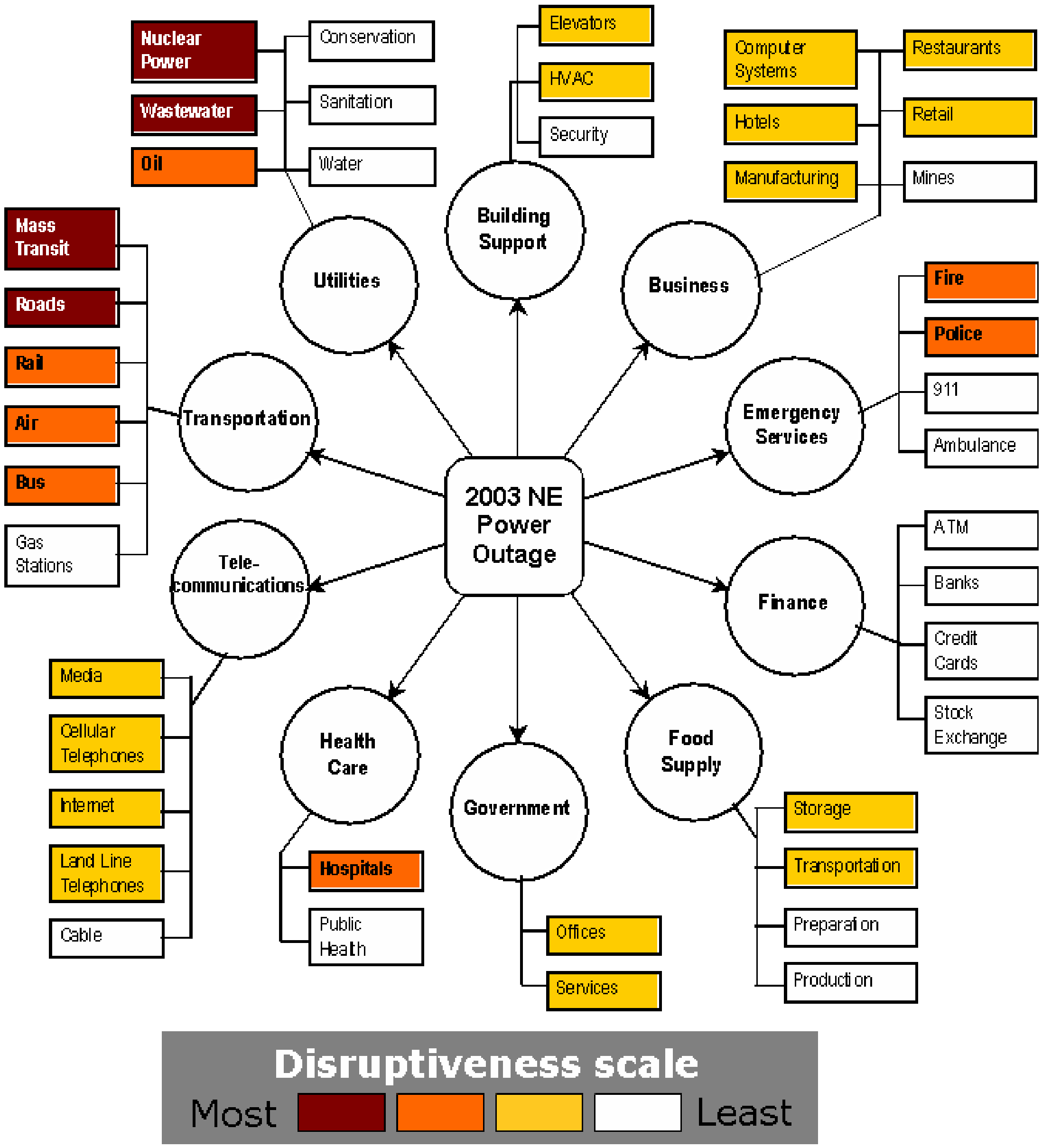

Figure 4. Impacts of the August 14, 2003 Blackout [Chang 2004].

Applicability of market principles to the definition of prioritization methodologies (in combination with other costs associated with disruption and restoration) is viewed by the authors of this study as a fruitful area for further analysis and research. As the magnitude and duration of a disruption increases, the potential increases for markets to realize economically efficient allocation of supply shortfalls. Economically efficient allocations of energy supplies are quite unlikely under all other schemes.

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